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FINAL PROJECT REPORT**

SOLAR ENERGY AND THE MOJAVE DESERT TORTOISE

Modeling Impacts and Mitigation

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Solar Energy and the Mojave Desert Tortoise: Modeling Impacts and Mitigation is the final report for the Desert Tortoise Spatial Decision Support System project (contract number CEC-PIR-10-048) conducted by the University of Redlands, Redlands Institute and the U.S. Fish and Wildlife Service, Desert Tortoise Recovery Office. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

Increasing energy production from renewable sources is a strategic priority for California and the nation. Large, utility-scale solar developments have been proposed for the Mojave Desert to help achieve this goal, and many more are anticipated. However, such developments have extensive land and water requirements, and they can have negative impacts on ecosystems and vulnerable species.

Protecting existing populations and habitat for the state and federally-listed Mojave desert tortoise, while implementing recovery actions to improve habitat quality, is also a high priority. Tools are needed to quantify the impacts of various developments and to determine the set of recovery actions and mitigation measures to compensate for those impacts.

To address this need, the University of Redlands and the U.S. Fish and Wildlife Service's Desert Tortoise Recovery Office developed a Geographic Information Systems-based decision support system. The system modeled the interrelationships among existing threats and their contributions to population change, and evaluated how those relationships are affected by proposed recovery actions. However, the original version did not explicitly incorporate potential changes in underlying threats, such as those resulting from new solar energy development.

This project expanded the original system to support environmental review of new solar energy development projects. Improvements to system models, calculations, and technology enable users to conduct spatially-explicit and fully documented combined impacts analyses of solar projects, and evaluate mitigation options for the desert tortoise. This project also developed a Web-based portal, where users can input solar energy development project footprints and run new impact and mitigation calculations.

Agencies are using the system to assess the probable impacts of individual solar energy development projects on the desert tortoise and potential mitigation actions. This supports agencies in making better decisions to promote conservation, while reducing uncertainty and delays in the permitting process for the benefit of California's ratepayers.

Keywords: endangered species, decision support, desert tortoise, GIS, mitigation, spatial analysis, solar energy, threats assessment, recovery actions, uncertainty, sensitivity, impacts, siting, permitting

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EXECUTIVE SUMMARY

Introduction and Background

California's natural and renewable resources are an important foundation for the state's past and future cultural and financial vitality. Efforts to balance the goals of economic prosperity, energy independence, social equity, and environmental health, sometimes create land use conflicts in specific regions, such as the Mojave Desert.

Among other qualities, the Mojave Desert represents a unique and fragile environment, a recreational asset, and a potential source of renewable energy through solar and wind energy development. The number and size of proposed solar energy development projects in the Mojave are increasing, stimulated by higher energy costs and by federal and state policies requiring energy generators to increase production from renewable energy resources in the coming decade.

The Mojave desert tortoise (*Gopherus agassizii*) is a long-lived, wide ranging species that is central to many conflicts over desert land use. Protected by state and federal laws as a threatened species, the desert tortoise is in decline due to a complex array of threats including habitat loss and degradation. These laws require proposed development projects to conduct an assessment of potential impacts to the desert tortoise and other listed species. Proposed projects must also develop strategies to mitigate for and reduce these impacts as part of the environmental review process, and to help the species recover a more stable status.

Recognizing the need to balance development with protecting endangered species, the U.S. Fish and Wildlife Service's Desert Tortoise Recovery Office and the Redlands Institute, at the University of Redlands previously developed a *spatial decision support system* for management and recovery of the Mojave desert tortoise. A decision support system is a method for breaking down a complex problem into its component parts, and identifying or modeling how those parts interact. Decision support systems also manage data, perform simulations and analysis based on the data and models, and provide system users with the most critical output information in a manner conducive to sound decision making.

The Desert Tortoise Spatial Decision Support System assesses the impacts of threats to tortoise populations across their range, and estimates the effectiveness of management (recovery) actions that may reduce or mitigate those threats. The system characterizes the interrelationships among threats, desert tortoise population change, and recovery actions. System models and Geographic Information Systems technology evaluate how these relationships are affected by proposed changes to the landscape. The system generates maps and reports of the risk to the desert tortoise population arising from existing threats, and the effects of recovery actions that mitigate those threats.

The review process for proposed energy development projects is often delayed where ecological impacts are not well understood, as is the case with the Mojave desert tortoise. As the number of pending applications grows, there is a pressing need to develop tools and processes that will

improve understanding of potential impacts and mitigation actions, and thereby support more efficient environmental review of new energy development projects.

Purpose

This project extended the Desert Tortoise Spatial Decision Support System to evaluate the impacts of new proposed solar energy development projects as an additional type of threat. The goal of this research was to reduce environmental conflict around solar energy development projects by helping regulatory and permitting agencies make more transparent and objective decisions that promote conservation, while reducing uncertainty and delays in the permitting process.

The primary objectives of the project were:

- To extend the original system to estimate the impacts of new, proposed solar energy development projects on the desert tortoise.
- To develop an interactive website where users can run new impact and mitigation calculations for their own proposed solar energy project footprint.
- To better inform users of the benefits of proposed mitigation actions relative to these anticipated impacts, by improving and sharing the models, data and science behind them.

The system will support a variety of users and decision makers, including but not limited to solar energy development project proponents, regulators, resource managers, conservation groups, and scientists.

Achievements

Work completed in this project extended the impact and recovery models to evaluate the specific direct and indirect impacts of solar energy development on the Mojave desert tortoise population at the project-specific scale. This effort involved incorporating new data, science and knowledge related to solar energy development projects and the desert tortoise, with input from and review by scientists, regulators, and desert tortoise stakeholders. The improved system models and calculations were assessed using proposed solar energy development project footprints.

The extended system can estimate the types and number of recovery actions that may offset the impacts of a solar energy development project. The system calculates the negative effects that could be caused by a proposed project, and the positive effects of proposed mitigation actions, with both measured as the change in risk to the tortoise population. This allows system users to make direct comparisons of the potential impacts and benefits of proposed projects, and to select appropriate types and amounts of mitigation actions.

The project partners completed the following system improvements:

- Improved the system's ability to assess the relative value of mitigation or recovery actions for the desert tortoise.
- Worked with partner agencies and stakeholders, including the Desert Tortoise Science Advisory Committee and the Desert Tortoise Recovery Implementation Teams, to incorporate the best available science and data, and revise system models to include the specific direct and indirect impacts of solar energy development projects.
- Tested the system by calculating impacts from a proposed solar energy development project and the associated suite of proposed recovery actions for mitigation.
- Improved programs so that the spatial computations are about ten times faster than in the original system.
- Implemented a first step in estimating uncertainty for the system's outputs to provide more complete information to decision makers.

This project also included the design and development of a Web-based *Desert Tortoise Recovery Portal* and associated online interfaces and tools that provide users with access to system data and models, and allow users to input solar energy development project footprints and run new impact and mitigation calculations. Prior to this project, running impact and mitigation calculations required considerable support by the project team. As part of this portal development, the team developed a set of tools for scientists, stakeholders and the public to explore and provide input on system models, data, and proposed recovery actions for the tortoise. They also developed an online tool for regulators and other users to: (1) input project parameters and calculate the impacts of specific solar energy development projects, and (2) interactively select proposed recovery actions from the recovery action database, and review their mitigation effects in relation to the solar projects impacts.

This project leveraged existing system components and improvements funded through other federal agency initiatives. The project also benefitted from engaging with other planning efforts, including the multi-agency Desert Tortoise Recovery Implementation Team process, which provided unique opportunities for validation of system models and data. In addition, desert tortoise scientific research funded by the U.S. Fish and Wildlife Service informed efforts to integrate formal population dynamics modeling into the system.

Challenges and Recommendations

The project partners identified a few key challenges and some specific, high-value analyses and technology development activities that could further enhance the system's utility for environmental review of solar energy development projects that could impact the desert tortoise. These activities would further strengthen the scientific basis of the underlying data, models and analysis, and provide more accurate outputs. In addition, they would improve system computational and reporting functions so that users could more rapidly and efficiently obtain estimates of impacts and evaluate mitigation actions.

Key challenges identified through this research are:

- Improving the modeling of large-scale processes such as population fragmentation in the system, to better address long-term impacts.
- Fully assessing the long-term and cumulative effects of numerous solar energy development projects in the desert.
- Incorporating improved land use models to better determine the mitigation effects of acquiring and conserving land to compensate for habitat loss caused by solar energy development projects.

To address some of these challenges and further enhance the system, the report recommends:

- Extending the models to better address the large and long-term cumulative effects from processes such as population fragmentation and climate change.
- Characterizing and integrating uncertainty for additional components of the system to provide a more comprehensive assessment of uncertainty around system estimates of risk to tortoise populations.
- Improving recovery action models to better assess the relative value of recovery actions at the project-specific scale.
- Improving system processes and user interfaces for design and selection of site-specific recovery actions as potential mitigation for solar energy development projects.

Conclusions

The Desert Tortoise Spatial Decision Support System provides critical support for users such as project proponents, regulators, resource managers, conservation groups, and scientists to assess the direct and indirect effects, both beneficial and adverse, of various activities and management actions on the desert tortoise. The system is helping to reduce conflict among multiple stakeholders by providing insights into the effects of the many desired uses of resources in the Mojave Desert.

Benefits to California

As the state energy demand continues to increase, seeking alternative sources of renewable energy is of vital importance. Initial assessments with the decision support system confirm that the new generation of large-scale solar energy developments could indeed have significant impacts on the recovery of the Mojave desert tortoise population. Therefore, it is ever more important to identify the most effective recovery actions that could mitigate for these impacts.

Through its focus on timely, science-based support for the environmental review process for solar energy development, this project helps to ensure that stable, secure and reliable sources of renewable energy can be provided to California ratepayers in an environmentally responsible manner.

CHAPTER 1: Introduction

1.1 The Challenge

1.1.1 Mojave Desert Tortoise: A Threatened Species

The Mojave desert tortoise (*Gopherus agassizii*) (Cooper 1863; Murphy et al. 2011; Figure 1) is listed as Threatened under the U.S. Endangered Species Act (USFWS 1990) and the California Endangered Species Act, and is considered a Species at Risk under California's Wildlife Action Plan (Bunn et al. 2006). Its decline is thought to be a result of a complex interaction of threats, including loss of habitat to development, reduced habitat quality due to alteration of plant species presence and abundance, increased predation, deliberate killing by humans, and increased disease prevalence.

Figure 1: Mojave Desert Tortoise

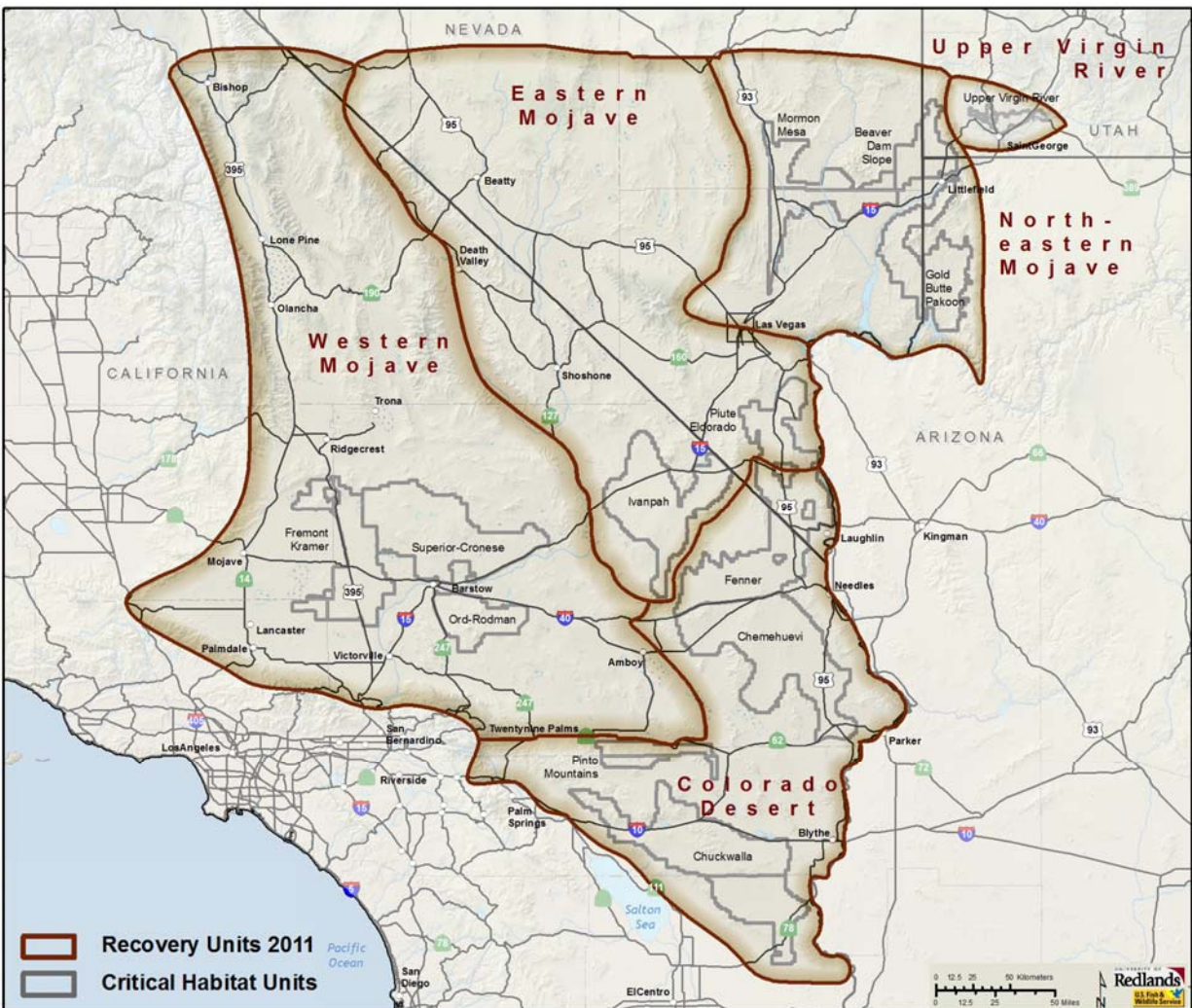


Photo Credit: U.S. Geological Survey (USGS)

The 2011 revised recovery plan for the Mojave desert tortoise (USFWS 2011) identified five recovery units that collectively cover the entire range of the species (Figure 2). Recovery units for the desert tortoise are special units that are geographically identifiable and are essential to the recovery of the entire listed population (i.e., recovery units are individually necessary to conserve the genetic, behavioral, morphological and ecological diversity necessary for long-term sustainability of the entire listed population). Critical habitat within each recovery unit was also designated under the U.S. Endangered Species Act (Figure 2), which identified the specific areas supporting those physical and biological features that are essential for the conservation of the species, and that may require special management considerations or protection. Over sixty percent (~4,000,000 acres) of designated desert tortoise critical habitat occurs on federal lands managed by the Bureau of Land Management.

Critical habitat and other management designations for desert tortoises included within “tortoise conservation areas” (TCAs) are the focal areas for management actions within each recovery unit (USFWS 2011). Effective recovery of sensitive species like the desert tortoise is predicated on identifying and reducing threats. Unlike species such as the bald eagle, where the threats to the species (primarily, the chemical compound DDT) were few, identifiable and relatively easy to remedy, the desert tortoise faces multiple, interacting threats (Doremus and Pagel 2001; Scott et al. 2006). The effects of these threats vary spatially and temporally across the tortoise’s range (USFWS 2010). Thus, a key to recovery of the Mojave desert tortoise is identifying, from among the diverse suite of potential threats, those most responsible for site-specific population declines, and implementing effective management actions that address those threats (Averill-Murray et al. 2012). For many potential threats to Mojave desert tortoise populations, effective management actions have not been identified or sufficiently implemented (Boarman and Kristan 2006; USFWS 2011).

Figure 2: Mojave Desert Tortoise Range



A map of the Mojave desert tortoise population range showing designated Recovery Units as of 2011, and critical habitat units. The range includes large areas of California and Nevada, and portions of Arizona and Utah.

Source: USFWS 2011

Desert tortoises are long-lived and grow slowly, requiring 13 to 20 years to reach sexual maturity, and they have low reproductive rates during a long period of reproductive potential (Turner et al. 1984; Bury 1987; Germano et al. 1994), presenting further challenges to species management and recovery (USFWS 2011). Because desert tortoises occupy large home ranges, the long-term persistence of extensive, unfragmented habitats is essential for the survival of the species. The loss or degradation of these habitats to urbanization, habitat conversion from frequent wildfire, or other landscape-modifying activities place the desert tortoise at increased risk of extirpation (USFWS 2011).

1.1.2 Solar Energy Development in the Mojave

As a protected species, and because their burrows provide shelter for other desert animals (Ernst and Lovich 2009), the desert tortoise serves as an *umbrella species* for the Mojave Desert ecosystem (Tracy and Brussard 1994). For this reason, the desert tortoise is central to many conflicts over desert land use, including concerns about habitat loss due to recent utility-scale renewable energy development (Lovich and Ennen 2011). Unfortunately, the landscape features that define good quality desert tortoise habitat for conservation and recovery (gently sloping terrain with sandy-gravel soils, where there is sparse cover of low-growing shrubs and high solar radiation) also define desirable locations for solar energy development, bringing these objectives into conflict. However, little is known about the actual impacts of solar energy development on this species.

The past decade has seen a rapid increase in the number and scale of proposed solar energy development projects for the Mojave Desert. To illustrate: the California Bureau of Land Management (BLM) states that they are reviewing over 20 right-of-way requests encompassing more than 125,000 acres for the development of solar energy projects for over 8,000 megawatts of electricity (CA BLM 2013). This growth in applications for solar energy development projects in the desert southwest is spurred by rising costs and demand for electricity, concerns about global climate change, and federal and state policies intended to promote energy independence and sustainability (Lovich and Ennen 2011). For example, California's Renewables Portfolio Standard (established in 2002 under Senate Bill 1078, accelerated in 2006 under Senate Bill 107 and expanded in 2011 under Senate Bill X1-2), requires investor-owned utilities, electric service providers, and community choice aggregators to increase procurement from eligible renewable energy resources to 33 percent of total procurement by 2020.

One way this standard is being met is through the development of utility-scale solar energy projects in the Mojave Desert. The 2005 Federal Energy Policy Act, which promotes development of renewable energy on federal lands, and the 2009 American Recovery and Reinvestment Act also have fueled interest in solar energy development in the Mojave Desert. In addition, the Desert Renewable Energy Conservation Plan, a collaborative effort between the California Energy Commission, California Department of Fish and Wildlife, the U.S. Bureau of Land Management, and the U.S. Fish and Wildlife Service, is working to streamline permitting for utility-scale renewable energy projects in the California Mojave Desert, and provide for the long-term conservation and management of significant biological species (DRECP 2012). The desert tortoise is one of the flagship species of the DRECP.

Every solar energy project must undergo lengthy environmental review and approval processes prior to construction, including those required by the federal National Environmental Policy Act (NEPA), the Endangered Species Act (ESA) and the California Endangered Species Act (CESA), as appropriate. As the number of pending applications grows, there is a pressing need for tools and methods that will improve understanding of potential impacts and mitigating actions, and thereby facilitate transparent, objective and more efficient environmental review of new energy development projects. Streamlined permitting of renewable energy projects will be

necessary in order to meet California's legal requirements as stated in the Renewables Portfolio Standard.

1.1.3 Impacts of Solar Energy Development on the Desert Tortoise

Based on the number and scale of solar energy development projects already in review, there is concern that their cumulative effects to the desert tortoise (and other Mojave species) may be of a magnitude never seen before, and may compromise the legally-required recovery of this species. Potential impacts include habitat loss, population and habitat fragmentation, changes in water flow, the introduction of pollutants, mortality by vehicle encounters, and alteration of the adjacent desert tortoise conservation areas through edge effects (Lovich and Ennen 2011). Edge effects in the Mojave Desert include proliferation of non-native and predator species, both of which are major threats to the desert tortoise (Boarman and Sazaki 2006).

Environmental review of recent solar applications in the Mojave Desert has raised several unresolved issues regarding the analysis and mitigation of potential impacts to the desert tortoise. Resource agencies typically recommend that unavoidable impacts to sensitive species be compensated through land acquisition at a ratio that offsets the impact. To date, many proposed solar energy developments in the Mojave have been sited in high quality desert tortoise habitat. Where these land-intensive developments are located on prime tortoise habitat, acquiring sufficient acreage of available and appropriate habitat compensation lands is becoming less viable. Most desert tortoise habitat is already in federal ownership, leaving very little remaining good habitat in private-ownership available for acquisition (Cameron et al. 2012).

In addition, the 2011 revised recovery plan for the desert tortoise prioritizes intensive management actions, such as habitat enhancement and actions to reduce mortality, within existing TCAs, most of which are managed by the Bureau of Land Management or National Park Service (USFWS 2011). Therefore, mitigation actions other than land acquisition are needed to offset negative impacts of California solar energy development projects on the desert tortoise. Implementation of priority recovery actions on already publicly-owned land designated for tortoise conservation, within the same recovery unit as the impact, is necessary for tortoise recovery. Also needed are rigorous methods to quantify the direct and indirect impacts associated with solar energy development and benefits of recovery actions for mitigation on the same measurement scale.

It is worth noting that siting solar energy development in areas of lower habitat value to the desert tortoise and other sensitive species could reduce impacts, mitigation requirements, and conflict related to biodiversity conservation in the Mojave. Recent studies suggest that there is sufficient compatible, low conservation value land available to accommodate California's solar energy targets (Cameron et al. 2012; Stoms et al. 2013). Whether located in high-value or low-value conservation areas, there remains the need for scientific methods and technology to evaluate and document potential impacts, and to develop appropriate mitigation strategies to offset these impacts resulting from solar energy development.

1.2 A Solution

1.2.1 Decision Support for Species Management and Recovery

The unique constraints attending to desert tortoise biology and ecology, the current state of scientific knowledge, the complex socio-economic and political landscape of the Mojave Desert, and the need to provide transparency in decision making, all were factors in the decision to develop and employ spatial decision support methods and technology for recovery and management of this species. A *spatial decision support system* (SDSS) is a method for breaking down a large problem into its component parts and identifying how those parts interact (Starfield 1997). In addition, they support decision making by presenting the decision maker with the critical information they require (Simon 1996). These systems employ computer technologies and involve relationships which use decision rules, models, databases, and formal representations of decision makers' requests to indicate specific actions to solve problems. Use of these systems allows different types and levels of information to be pooled, compared, weighed, and interpreted. Developing and applying a decision support system makes it apparent where information is missing and where there is a need for research or monitoring programs (Starfield and Bleloch 1991), and can improve the efficiency of decision processes (Ekbja 2004).

1.2.2 Project History and California Energy Commission-Funded Research

This project builds on more than a decade of applied research on the Mojave desert tortoise by the project partners, with funding from the U.S. Fish and Wildlife Service (FWS) and the Department of Defense Army Research Office, and in collaboration with multiple stakeholders including the Desert Tortoise Management Oversight Group, California Desert Managers Group and other local, state and regional groups. In 2007-2009, the FWS Desert Tortoise Recovery Office (DTRO) and the University of Redlands' Redlands Institute (Redlands) hosted several stakeholder workshops to create a lexicon of threats, recovery actions, and mortality mechanisms, and a core system engine that prioritized non-spatial recovery actions based on spatial distribution of threats.

In 2007-2010, the DTRO and Redlands began work on the models and calculation engine for a Desert Tortoise Spatial Decision Support System (SDSS). This work involved the construction of the model framework for the Mojave desert tortoise (Darst et al. 2013), using the standard lexicon for biodiversity conservation (Salafsky et al. 2008). It also involved collecting, compiling, and processing the massive amount of spatial data necessary to support the system models, with a particular focus on threats and recovery actions. During this time the project partners piloted the use of Web-based tools for stakeholders and the public to explore system data and models, and developed the system through two iterations. Currently funded collaborative research focuses on the existing landscape of threats to the species across the four state range of the desert tortoise (California, Nevada, Arizona and Utah), and methods and strategies for alleviating those threats.

Funding from the California Energy Commission in 2011-2013 allowed DTRO and Redlands to leverage and expand on the pre-existing system, to evaluate and estimate the increase in risk to

the desert tortoise population that the spatial-temporal effects of planned or proposed solar energy development projects would pose. A significant benefit of this project derives from combining this new capability with the system's existing ability to estimate the reduction in risk from suites of site-specific recovery actions that could be implemented as mitigation for large-scale development projects. Since both calculations provide estimates on a common scale, direct comparison of the increase and decrease in risk to the tortoise population provides valuable and timely information to developers and regulators alike. Development of this third system iteration focused on the enhancement of the system models, spatial data, calculation engine, and tool functionality to support energy-related needs **not** addressed by the pre-existing system.

1.2.3 Overview of the Desert Tortoise Spatial Decision Support System (SDSS)

The Desert Tortoise SDSS quantifies the impacts of threats to tortoise populations and estimates the effectiveness of recovery actions that are most likely to ameliorate those threats. The system contains a series of models that describe:

- The direct and indirect effects of threats to tortoise population change (i.e., which threats cause other threats, and how these threats increase stresses on tortoise populations).
- Recovery action-to-tortoise population relationships (i.e., what are the most effective actions given a set of population stresses faced by the species).

Using geospatial data of the spatial extent of threats and the spatial variation in the probability of desert tortoise presence (Nussear et al. 2009; Fry et al. 2011), the system estimates the direct and indirect effects of threats to the population, and the effectiveness of recovery actions at ameliorating these threats based on contributions to changes in risk to the population, where risk refers to overall population change (Darst et al. 2013).

Changes in risk to desert tortoises can come in the form of threat increase (e.g., installation of a large-scale solar energy development project, or expansion of a military base within tortoise habitat) or threat decrease (e.g., undertaking a suite of recovery actions within tortoise habitat). Because there are few data available to quantify the *absolute* effects of different threats on desert tortoise populations (Boarman 2002; Boarman and Kristan 2006; USFWS 2011; Averill-Murray et al. 2012), the system estimates the *relative* impact of threats and *relative* effectiveness of recovery actions based on their predicted effect on risk to the population (Darst et al. 2013).

All changes in risk result from changes in stresses to the tortoise population and are calculated on a common scale. This allows for comparison of how much of an *increase* in risk to the population due to threat increases (e.g., new roads) could be offset by *reduction* in risk from threat decreases (recovery or mitigation actions). The ability to compare threats and recovery actions on a common scale of risk to the population is a unique and important benefit, and is central to the system's utility for informing the environmental review of solar energy projects. The system provides decision makers with useful information regarding the effectiveness of alternative recovery actions for addressing the impacts of proposed solar energy projects.

Thus, the Desert Tortoise SDSS provides structured decision support for assessing the impacts of potential solar projects on the tortoise and quantifying the benefits of proposed mitigation strategies, including off-site management actions needed for desert tortoise recovery. Off-site actions are needed because solar energy development projects in the desert result in total habitat loss within the project footprint (due to land-intensive activities such as grading, fencing, etc.). In addition (as noted above), the typical mitigation strategy of acquiring habitat compensation lands at a ratio that offsets the impacts is problematic, given current land use and ownership, and species recovery priorities (USFWS 2011). Thus, off-site actions to protect existing populations and habitat, and improve habitat quality within those areas, should be considered for mitigation. The project partners are addressing this issue in part by accessing a bank of spatially designed recovery actions being compiled through in a parallel project managed by the FWS.

1.3 Outline and Objectives of the Report

This Final Report documents the results of this research activity. The report objectives are to:

- Describe the origins, science and technology employed in the iterative development of the Desert Tortoise SDSS, and the state of the system prior to Energy Commission funding (**Chapter 2**).
- Provide more detail on the system models and core calculations that lay the groundwork for advances to the system achieved with Energy Commission funding (**Chapter 3**).
- Describe the actions taken to extend and enhance the pre-existing system for calculating impacts and recovery actions related to solar energy development (**Chapter 4**).
- Discuss significant assumptions, challenges encountered in completion of the research, and recommendations for the future extension and application of the Desert Tortoise SDSS (**Chapter 5**).
- Provide supporting documents and additional detail on scientific approaches and calculations used in the system, in the **Appendices**.

A few conventions are used in this report to help the reader:

- Terms that have a particular meaning in the context of this project and the Desert Tortoise SDSS are presented in *italics* and defined in the text where introduced. They are also defined in the **Glossary of Terms**.
- Specific examples of threats, stresses, or recovery actions from the Desert Tortoise SDSS are included using quotations and capital letters, following the convention used in the system: e.g., the threat “Motor Vehicles on Paved Road.”
- The threats, stresses, population effects and recovery actions included in the system’s model framework (conceptual model) are summarized in Table 2 in Section 2.4.1, and presented in full in **Appendix A**.

CHAPTER 2:

The Pre-Existing Desert Tortoise SDSS

2.1 A System for Recovery Action Evaluation

Chapter 1 illustrated why the desert tortoise is a challenging species for which to build a useful, computational model that can estimate the relative effectiveness of site-specific recovery actions. Consequently the project partners adopted an iterative approach to building and improving the Desert Tortoise SDSS over time. This chapter describes the first two iterations of the system completed by 2010, prior to the California Energy Commission funding for the current project. Chapter sections outline the core requirements, assumptions, and approaches associated with the evolving system, and provide essential background to clarify system improvements made in this project as described in Chapters 3 and 4.

2.1.1 Early System Design Directives

In 2006, the FWS DTRO determined that a spatial decision support system could facilitate the revision of the desert tortoise Recovery Plan. The core objective of the system was to use the best available science and relevant data to support the relative comparison of proposed, site specific recovery actions. To be useful in revising the Recovery Plan, the system had to be operational within months, and bring together scattered, incomplete and often contentious science. The system needed to be both comprehensive and transparent so that estimates of the relative effectiveness of recovery actions could inform decisions made by the diverse agencies, counties and municipalities managing the public lands where the desert tortoise lives.

The DTRO worked with the U.S. Institute for Environmental Conflict Resolution to develop a strategy for engaging scientists, land managers, regulators, nonprofit organizations and the public in designing the decision support system. The DTRO engaged researchers at Redlands to develop the Desert Tortoise SDSS technology. Redlands was selected based on their prior work on desert tortoise science and expertise in technology development using Geographic Information Systems (GIS) and science.

After several workshops, the project partners determined that the first iteration of the system would focus on estimating the effectiveness of recovery actions on reducing mortality to the tortoise population across the range. Ranking recovery actions by predicting their effectiveness at decreasing mortality was a first step towards a Muticriteria Decision Analysis (MCDA) approach in which additional decision criteria, such as costs, funding sources, and level of public support, could be incorporated into the prioritization (Kiker et al. 2005). While no single MCDA model could fit the heterogeneous management context of the desert tortoise's four-state range, recovery action effectiveness would be a critical criteria in all such models.

In the longer term, development of this system was the basis for a continuous workflow of estimating the effectiveness of recovery actions, implementing them, monitoring their effectiveness, comparing observed population response against the system's predictions, and analyzing discrepancies. Such a workflow would support both the adaptive management of the

desert tortoise species (USFWS 2011) and the iterative improvement of the system's data, process and change models.

The Desert Tortoise SDSS was designed to be range wide, comprehensive and transparent. At the time, the most available (or acquirable) information was related to threats facing the desert tortoise. Range-wide population data and mortality data existed but were too sparse to use in system calculations. The desert tortoise as a species faces many threats over its large range, and the intensity of the threats varies across the range, precluding attempts to build a decision model based on only a few significant threats. The requirements then were for a spatial computational system that would estimate risk to the population based on current threats.

2.2 First Iteration of the SDSS: 2006-2008

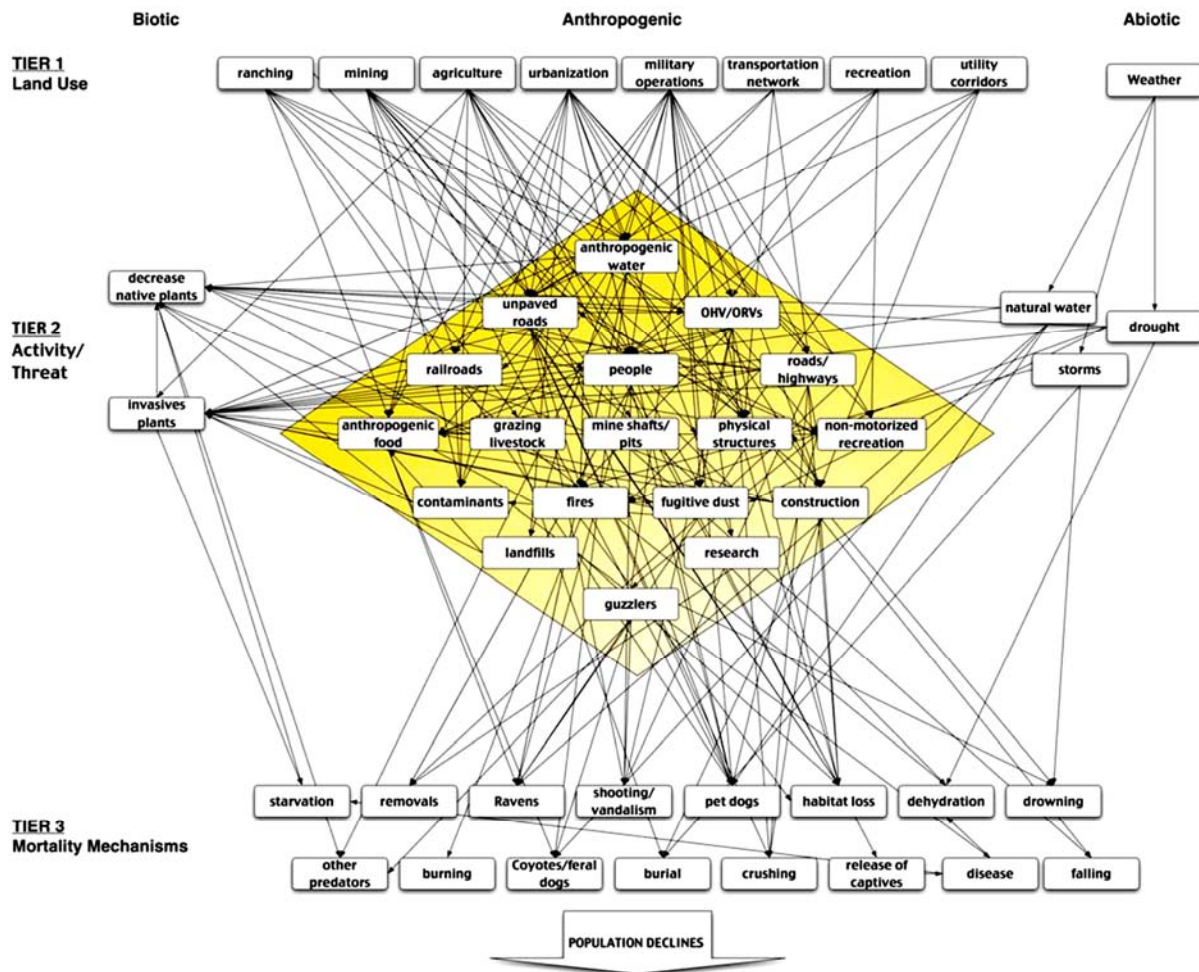
2.2.1 Conceptual and Computational Models

The Desert Tortoise SDSS uses a *conceptual model* to represent interacting threats, and the pathways connecting threats and recovery actions to overall population change for the desert tortoise (Darst et al. 2013). The most common threat and recovery action names and descriptions are provided in Table 2 of Section 2.4.1; a complete list is included in Appendix A.

In computer science, a *conceptual model* is a representation of the terms and concepts used to describe a complex problem within a particular subject or domain. Conceptual models are useful for clarifying the meaning of various terms and identifying the relationship among terms and concepts within the problem space. By documenting and visualizing important concepts and their interrelationships, and describing assumptions and expected outcomes, conceptual models can bring structure and transparency to the calculation of the impacts of threats and effectiveness of recovery actions, and assist multiple stakeholders contributing to the model in reaching a common representation of the problem.

The first version of the system conceptual model dealt only with the contributions of threats to mortality of adult tortoises, and the effectiveness of recovery actions in reducing that overall mortality. The model reflected all linkages from threats to mortality, and threats to threats (e.g., the threat that is "Surface Disturbance" gives rise to the threat that is "Fugitive Dust") as identified by Tracy et al. (2004; Figure 3). This decomposition of the aggregate effect of threats to population effects is widely used in species recovery models (Foundations of Success 2008). Conceptually, recovery actions were modeled by linking them to the specific threats that they suppressed.

Figure 3: Threats to Mortality Linkage Matrix



In this conceptual model of desert tortoise population decline, land uses give rise to threats and activities that can contribute both to themselves, and to mortality mechanisms. The mortality mechanisms combine to drive overall mortality. This diagram was the basis for the conceptual model of the first iteration of the Desert Tortoise SDSS.

Source: Tracy et al., 2004

Computational models contain mathematical equations or algorithms that simulate natural processes and use a set of input parameters to predict the outcome of these processes. In the Desert Tortoise SDSS, the computational model expresses the elements and input parameters of the conceptual model as algorithms, which are then executed using GIS and other software programs.

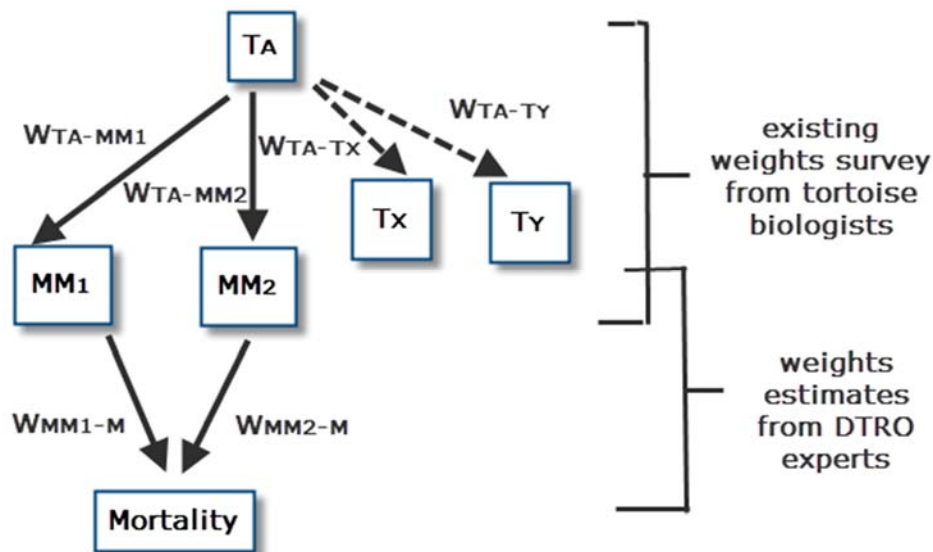
For this first iteration of the system, the *computational model* was simple. The project partners elicited from experts estimates of weights for the relative contribution of each threat to adult mortality, such that each linkage in Figure 3 was represented by a numerical contribution. Adult mortality was treated as a proxy for risk to the tortoise population. Each threat in the linkage matrix was represented by a range-wide map layer whose value at each point represented the intensity of the threat at that point. At every point on the range, risk to the

tortoise population was estimated as a weighted sum of the threats that contribute to adult mortality (contribution to mortality).

2.2.2 Weights Elicitation and Derivation

Quantitative estimates for the relative contributions of threats to risk for the tortoise population were not available in the scientific literature (Boarman and Kristan 2006). However, the approach described above provided for the possibility of empirical observation eventually delivering such values for different relationships in the model. An existing 2007 survey of desert tortoise biologists provided an initial set of expert weights for the relative contribution of (1) threats to other threats; and (2) threats to mortality mechanisms. In addition, DTRO biologists provided range-wide estimates of the contributions of individual mortality mechanisms to overall mortality (Figure 4).

Figure 4: Schematic of the Conceptual Model for the First Iteration SDSS



This schematic shows Weights (W) for Threats (T) to Mortality Mechanisms (MM), Mortality Mechanisms to Mortality and Threats to Threats (dashed lines). It also introduces the formalism used to label individual weights. The values for the weights were based on a 2007 survey of desert tortoise biologists and those provided by DTRO biologists.

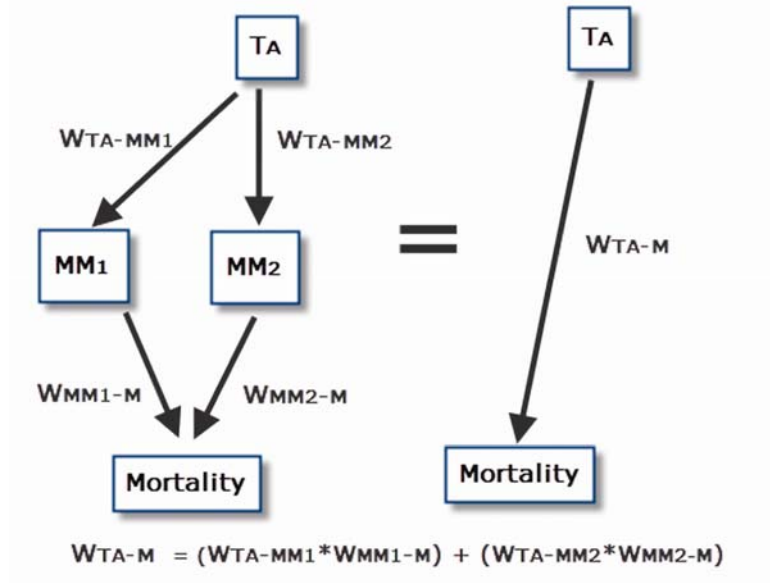
Source: Desert Tortoise SDSS, First Iteration

For example, “Motor Vehicles on Paved Roads” constitute a threat (T_A) to the tortoise that can lead to mortality through mortality mechanisms (MM_1) such as accidental or deliberate “Crushing” (USFWS 1994). Having vehicles on paved roads can lead to other threats (T_x, T_y) such as “Motor Vehicles Off-Route” (USFWS 2010), “Ravens” (attracted to road kill; see Boarman 2002) and “Invasive Plants” (Brooks and Lair 2005).

Weights for paths in multilevel linkage hierarchies were combined by taking their product along each link in the path (Golden et al. 1989, Saaty 1992). Combining the two sets of expert

weights provided by biologists, the system calculated the direct contribution of each threat to overall mortality of adult desert tortoises. This calculation is the *direct weight* for each threat: the estimate of how much that threat contributes to range-wide tortoise mortality (Figure 5).

Figure 5: Calculation of Direct Weight for a Threat



This schematic shows the direct Weight (W), derived by combining two sets of expert weights, of a Threat (T) to Mortality Mechanisms (MM) and to overall Mortality of the desert tortoise population.

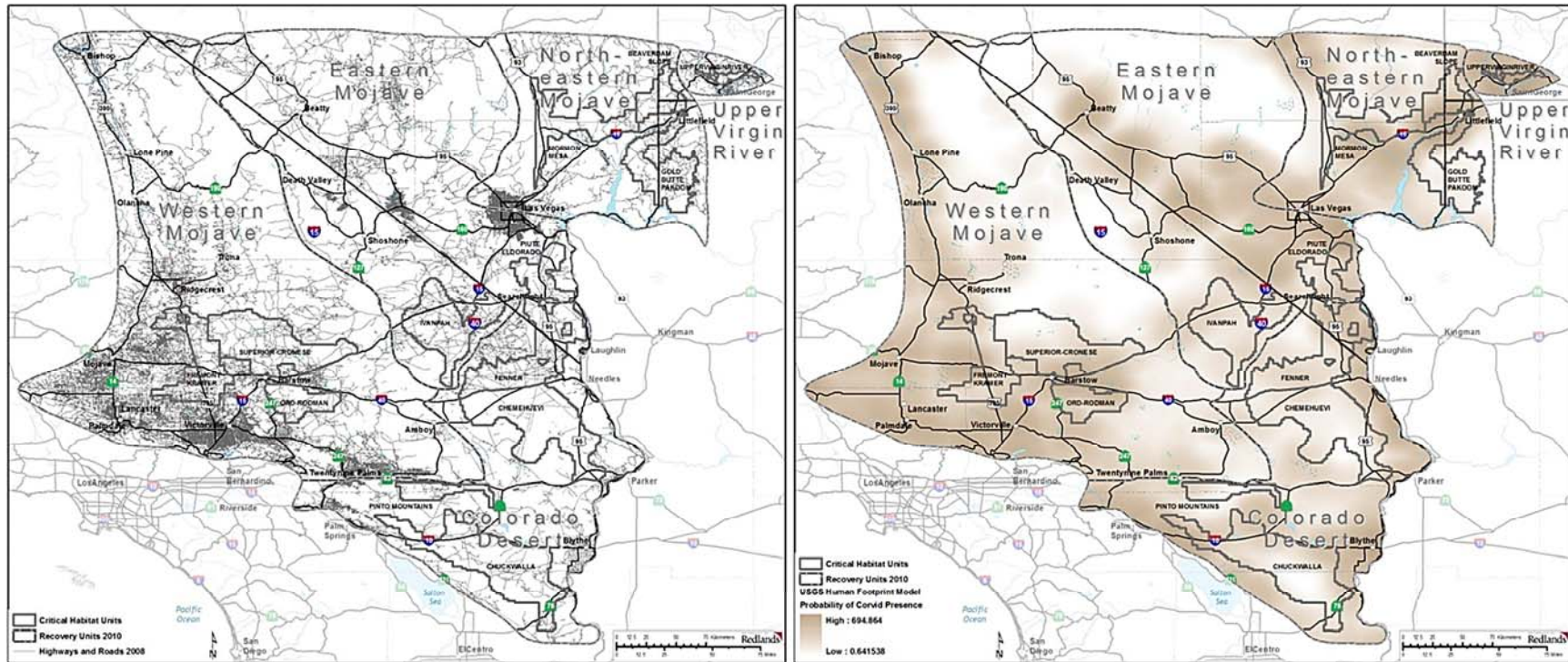
Source: Desert Tortoise SDSS, First Iteration

Note that the contributions of threats to other threats did not play a role in estimating the current contribution to mortality, and so are not discussed in any detail here. However, these threat-to-threat contributions can be used to provide a more comprehensive estimate of the contribution of a specific threat to overall risk to the population (Darst et al. 2013) and were employed in the combined impacts analyses described in Chapter 3.

2.2.3 Spatial Computations

As noted above, each threat in the Desert Tortoise SDSS model corresponds to a range-wide map layer whose value at each point represents the intensity of the threat at that point. This *threat intensity layer* is either an extent (a footprint) or a map layer with differing values at different points. In the former case, the threat intensity values would be binary, encoding as 1's and 0's indicating the presence or absence of a threat at a location. In the latter case, the threat intensity values would be continuous, represented as a road category, a density of ravens, or the number of fires recorded in that area (Figure 6). In any given area, the different threats are more or less present according to their spatial distributions. However, each threat intensity map could be on a completely different scale, complicating direct comparisons among maps.

Figure 6: Examples of Continuous Threat Intensity Layers



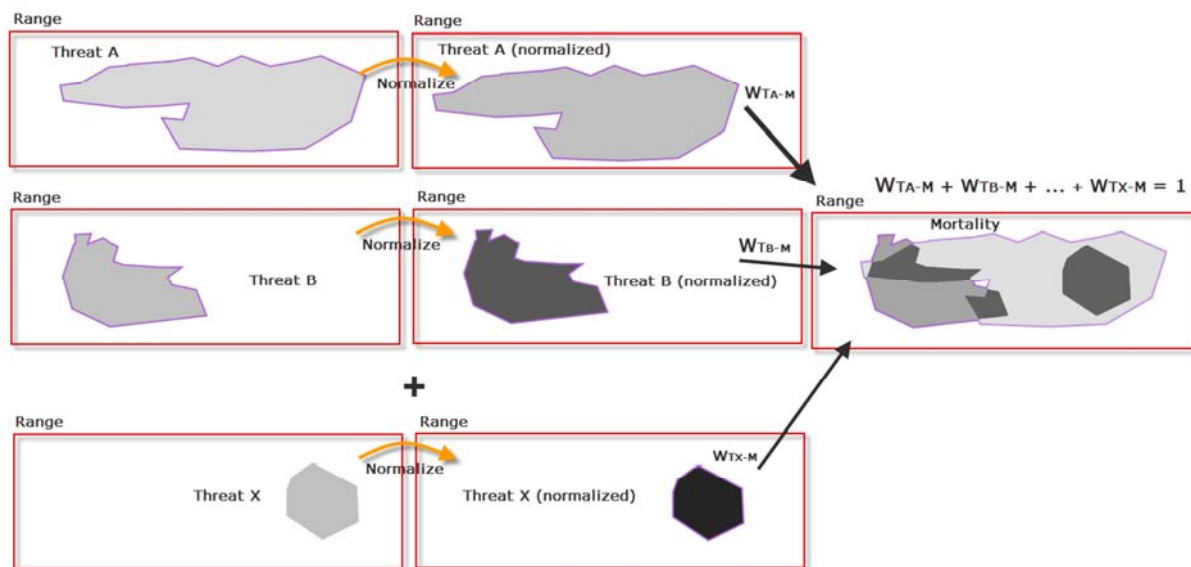
Examples of continuous threat intensity layers: “Paved Roads” (left) and “Ravens” (corvids; right).
 Source: Highways and Roads 2008, USGS Human Footprint Model, Probability of Corvid Presence (Leu et al. 2008)

To use the direct weights from each threat to overall mortality, assuming direct comparisons between threats, all threat intensity maps had to be converted to the same scale. The project partners employed a standard approach from (aspatial) decision analysis called Analytical Hierarchy Process (AHP; Saaty 1992, Saaty 1999). The AHP method was developed to choose among alternatives that are rated against multiple, weighted criteria. In order for the weights to play a role in the overall decision commensurate with how they were elicited, the original scale of each criterion, regardless of its units, was converted to a scale where all the alternatives' values on that rescaled criterion summed to 1.

Following this AHP methodology, the Desert Tortoise SDSS calculates a *normalization factor* for each threat intensity layer as the sum of the intensity values of the threat layer at every point over the entire range. It then divides the values of the original threat layer by the normalization factor to create the normalized threat layer, whose values are now dimensionless and sum over the entire range to 1. This approach guarantees that if the experts estimated that a threat contributes a percent w to overall mortality, then when the normalized threat map layer, multiplied by that weight w , is summed over the entire range, it does account for w of range-wide mortality. This spatial normalization that supports range-wide weights was used throughout all iterations of the system.

For each normalized threat layer, the system uses the direct weights to estimate risk to the tortoise population as a *weighted overlay* (Esri 2011) of all threats that contribute to mortality (Figure 7).

Figure 7: Spatial Calculation of Contribution to Mortality in the First Iteration SDSS



First, all the threats layers were spatially normalized individually. Second, at every point their values were multiplied by their direct threat weight. Third, the values from all threats were summed to produce an estimate of contribution to mortality at each point in the range.

Source: Desert Tortoise SDSS, First Iteration; Esri 2011

A word of explanation may be useful on the schematic diagrams, such as Figure 7, that are used to describe spatial operations. The red rectangle represents the entire desert tortoise range, and its repetition reminds the reader that all layers are defined over the full range, whether as inputs or outputs. For purposes of description, a spatial layer is depicted as containing one or more polygons. The grey intensity of the polygons is meant to suggest the value of the layer at a given point on a scale of 0-1: the darker the grey, the higher the value. (In reality, threat intensity layers and all layers calculated from them can vary spatially within their footprint.)

Consider the operation of spatial normalization, where the original threat intensity values are scaled so that the values of the normalized threat layer will add to 1 when summed over the entire range. If a threat is very widespread or continuous (e.g., Threat A might be “Ravens”), the normalization leads to a relatively low value at each point. On the other hand, for a highly localized or discrete threat (e.g., Threat X might be “Solar Energy Development”) normalization leads to a relatively high value at every point, since those values, which are summed over an effectively much smaller area, must still add to 1. Weights are always less than or equal to 1, so when a layer is multiplied by a weight, it will result in a new layer with equal or lower values: the result has a lighter grey than the input.

2.2.3.1 Relative Contribution of Threats in an Area

In all iterations of the Desert Tortoise SDSS, threat-to-threat weights were used to estimate the total relative contribution of each threat to overall mortality (and in the second and third system iterations, the contribution to risk to the tortoise population). That contribution, whether direct or indirect when the threat contributes to other threats, contributes in turn to mortality mechanisms. This allowed the system to generate rankings for threats in a given area by their total contribution to mortality (and later, risk to the population). Accounting for the indirect effects involves following all pathways from the original threat to mortality, and is done aspatially in a manner described in Darst et al (2013), and in more detail in Chapter 3. The result is a combined indirect weight, which when added to the direct weight described above, gives the total weight for the threat. Multiplying the original, normalized footprint of the threat by that total weight gives a weighted footprint that estimates the total contribution of that threat to mortality at every point on the landscape. When the values of the weighted footprint of a threat at each point for a specified area are summed, and the calculation is repeated for all threats, those sums can be used to rank the threats within that area. Such rankings can be important for regulatory purposes and for prioritizing research, but they do not provide insight on the impacts and mitigation calculations that concern this project, and will not be discussed further. In Chapter 3 threat-to-threat weights will play an important role in calculating the impacts on risk to population when a threat is **changed**, such as when predicting the effect of adding a new threat to the landscape (e.g., utility-scale solar energy development).

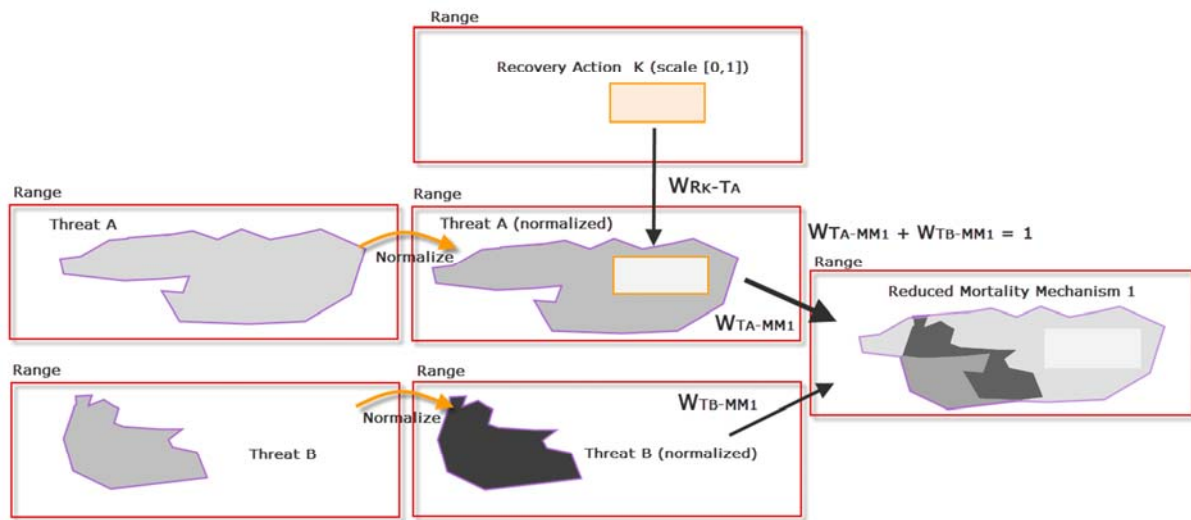
2.2.4 Recovery Action Models

Based on literature and surveys conducted at the initial workshops (Murphy et al. 2008), the project partners established a list of 20 recovery action types (e.g., tortoise fencing along roads, installation of off-highway vehicle route signs) along with a matrix of which of the ~30 threats each recovery action affected. Workshop participants individually estimated an *effectiveness*

weight for each link in that matrix; a final value was calculated by taking the mean over all participants. An effectiveness weight of 1.0 between a recovery action and a particular threat meant that the recovery action would completely eliminate that threat where the recovery action was implemented (100 percent effective). A weight of 0.5 meant that the recovery action would only reduce that threat's intensity by 50 percent.

The recovery action itself is represented as an area with implementation values at each point between 0 and 1, where 1 represents the recovery action being fully implemented at that point. Within this area, implementing the recovery action at any point reduces the intensity of each threat at that point according to the product of its effectiveness weights for that threat times its implementation value (Figure 8).

Figure 8: Reduced Threat Intensity from Implementation of a Recovery Action



When Recovery Action K (R_K) is implemented in an area where Threat A (T_A) occurs, it reduces Threat A by a fraction given by the effectiveness weight W_{RK-TA} .

Source: Desert Tortoise SDSS, First Iteration

To calculate the decrease in contribution to mortality expected from implementing a particular recovery action, the system multiplied the contribution of every *affected threat* in the area where that recovery action is implemented by the effectiveness weight for that recovery action acting on that threat. The reduction in affected threats reduced any mortality mechanism to which the affected threats contributed, which in turn reduced mortality. The contribution of each threat to relative mortality is reduced by the effectiveness weight of the recovery action on the threat. The system summed across all reductions in affected threats, at every point, to estimate the overall reduction in contribution to mortality due to that recovery action. Recovery actions could then be compared based on their overall contribution to a decrease in mortality, providing decision support for recovery planning.

2.2.5 Summary of the First Iteration SDSS

The assumptions, methodology and computational approach established in this first iteration (2006-2007) set the framework for the subsequent system development. The core Desert Tortoise SDSS requirements were to:

- Use spatially varying threat intensity layers defined for the entire range as inputs.
- Quantitatively express conceptual models to estimate the relative contributions of threats to overall mortality.
- Generate spatially varying estimates for relative levels of mortality across the range.
- Quantitatively express conceptual models for how a recovery action suppresses specific threats.
- Generate spatially varying maps estimating how much relative mortality is reduced by site-specific recovery actions.

Core assumptions behind the first iteration of the system included:

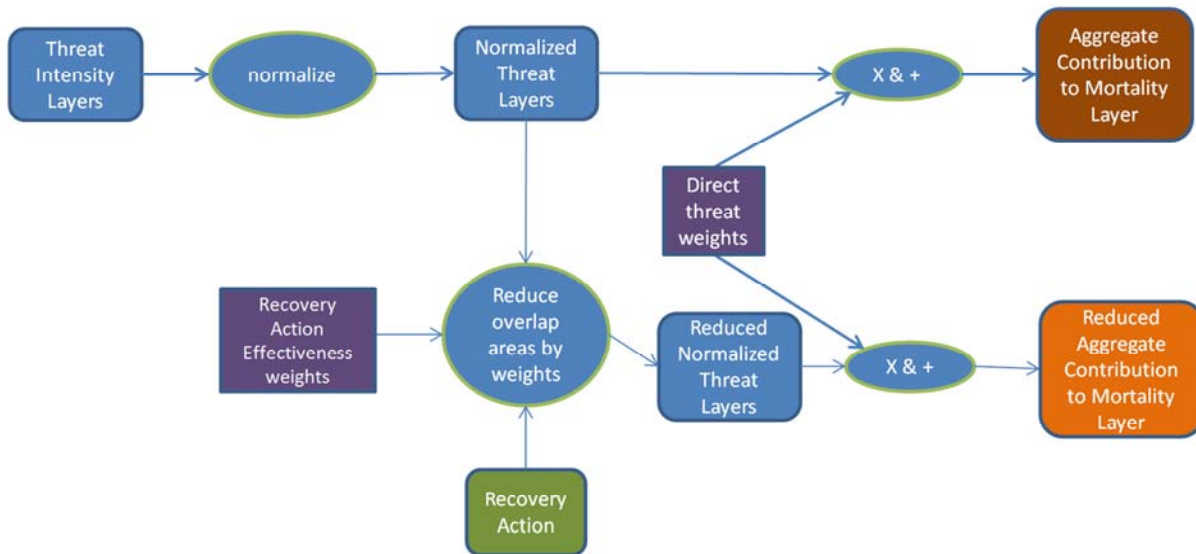
- All mortality within the desert tortoise population is accounted for by the threats in the model.
- The desert tortoise population density is constant across its range. This assumption is not intrinsic to the system, but was necessary during the first iteration because of the lack of range-wide population density values.
- Sufficiently accurate, range-wide intensity maps could be obtained for all threats that were considered to have significant contributions to mortality (at least in some part of the range).
- Total threat to the species can be linearly decomposed into threats that contribute to mortality and threats that contribute to other threats.
- Indirect effects of threats always provide a finite contribution to overall mortality, even in the presence of threat to indirect threat loops (no divergent feedback loops).
- Realistic weights to support this calculation can be obtained through expert elicitation.
- Recovery actions are immediately effective in suppressing threats (the model is atemporal).

To summarize the core computational approach of the first iteration of the Desert Tortoise SDSS:

- (1) Generate spatial maps of the intensity of each identified threat.
- (2) Normalize each individual threat layer across the range, so that all threat intensity map layers are on the same scale.

- (3) Multiply each normalized layer by the direct weight that is an estimate of how much that threat contributes to range-wide mortality.
- (4) Sum the values of the normalized, weighted threats at each point on the map, to arrive at an estimate of the relative aggregate contribution to mortality at each point across the range.
- (5) Obtain footprints for where recovery actions would be implemented, where available.
- (6) Where each recovery action's footprint overlaps with a threat that it reduces, multiply the threat's value by the associated recovery action effectiveness weight. This produces a set of layers whose value at every point is an estimate of the reduced normalized threat due to that recovery action (Figure 9). If a threat is unaffected by the recovery action, its normalized threat layer is unchanged.
- (7) For each recovery action, multiply those reduced (or not) normalized threat layers by the threat's direct weights, and sum the values over all threats. This produces a layer whose value at every point is an estimate of reduced aggregate contribution to mortality due to that recovery action (Figure 9).
- (8) Compare, spatially and numerically, reductions in aggregate contributions to mortality, due to each recovery action to determine which recovery actions are estimated to be the most effective.

Figure 9: Workflow to Calculate Reduced Aggregate Contribution to Mortality



This diagram shows the workflow for calculating the reduction in aggregate contribution to mortality due to the implementation of a single recovery action.

Source: Desert Tortoise SDSS, First Iteration

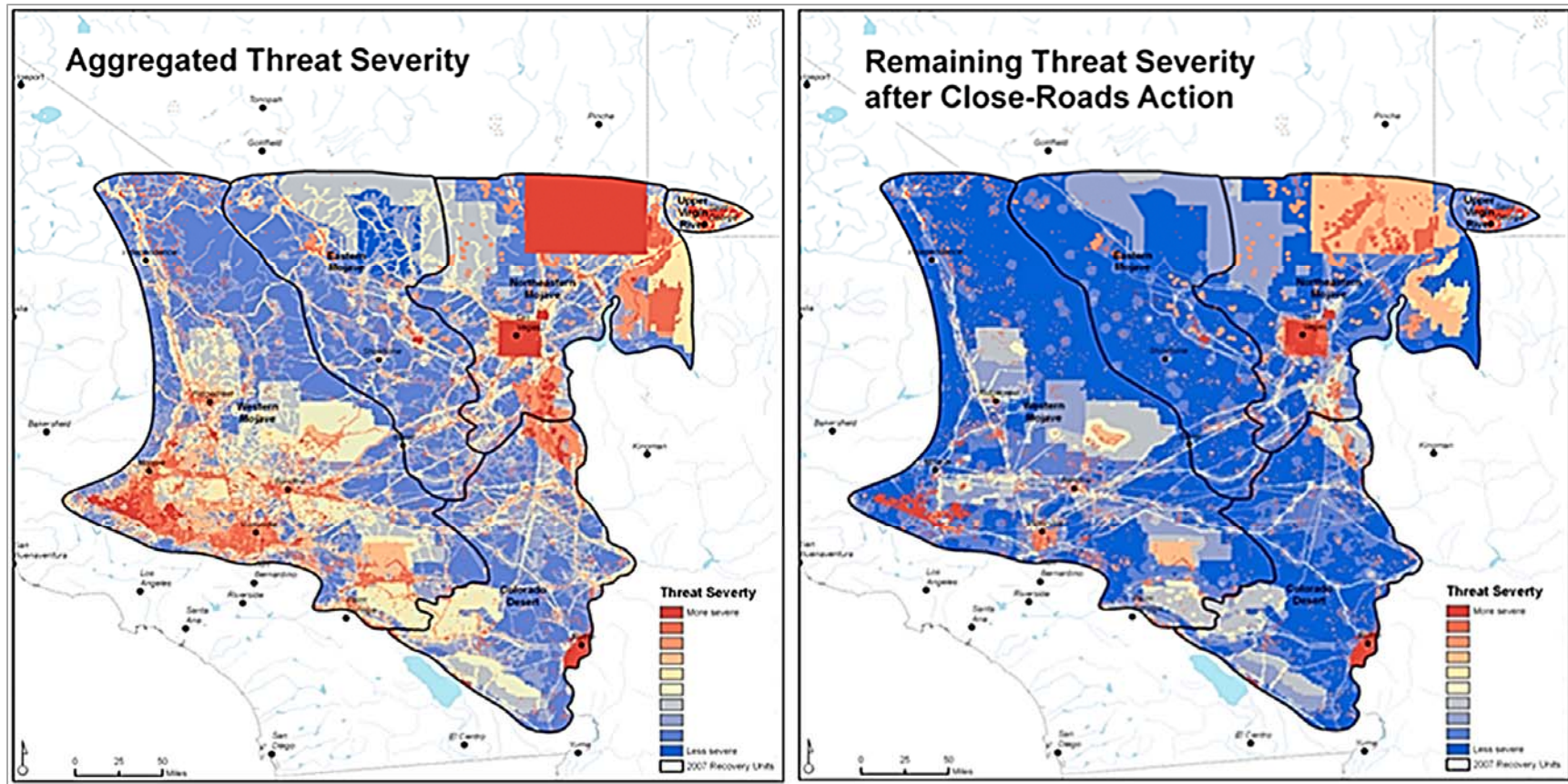
This first iteration of the Desert Tortoise SDSS was developed on Esri's ArcGIS® platform, using ArcGIS ModelBuilder® together with various geoprocessing tools and custom scripts. The threat-to-threat and threat-to-mortality mechanism weights were captured in Excel from a

pre-existing expert weights set. The tortoise mortality mechanism to adult mortality weights models were developed on a 9 to 1/9 AHP scale in Excel, then converted to direct weights using Criterium DecisionPlus®, and the recovery action effectiveness sub-model was developed using Microsoft Excel. A mathematical description of this iteration of the system is provided in the paper by Murphy et al. (2008).

2.2.6 Results from the First Iteration

For many threat types, information about where a threat is likely to occur across the range came from workshop participants who sketched the threat footprints on maps. Other available spatial data were rarely range-wide, and often reflected jurisdictional boundaries, which would require gross interpolation to be useful. Site-specific recovery actions on any meaningful scale were generally unavailable. While the system was successfully tested for a number of site-specific examples of recovery actions (e.g., placing tortoise fencing along roads, adding law enforcement rangers, and closing grazing allotments), the team learned that there were no range-wide datasets of already implemented or designed recovery actions that could be used to test the system across the entire range. Therefore, for this first iteration, the project partners looked at scenarios where each recovery action in turn was implemented range wide. Using the available spatial data and range-wide recovery actions, the system calculated a first set of qualitatively coherent spatial results, in which simplistic footprints for threats resulted in visible artifacts in the map layers of aggregate contributions to mortality (Figure 10).

Figure 10: Example of Aggregate Contributions to Mortality Map from the First Iteration SDSS



Map result from the first iteration, showing aggregated contributions to mortality before and after implementation of the recovery action of "Designate and Close Roads."

Source: Desert Tortoise SDSS, First Iteration

2.3 Iterative Approach to Developing the Desert Tortoise SDSS

Because a working version was needed within a few months, the project partners chose to implement the simple linear contribution to mortality matrix model described above for the first iteration. Maintaining the conceptual model as part of the computational system approach allowed for future iterations of the model, in which more accurate process models could replace different sub-networks in the current model. The project partners also realized that the quality and extent of the spatial data immediately available would vary considerably among the threats in the model. Again, only an iterative development approach was feasible: acquire the best datasets available; where possible stitch and interpolate localized datasets together to obtain range-wide datasets; and demonstrate how issues in the data produce anomalies in the results, so as to encourage project stakeholders to develop better threats datasets.

To ensure that successive iterations of the Desert Tortoise SDSS would be of higher quality, the project partners: (1) continually compared newly available datasets against current datasets looking for higher quality, range-wide datasets, (2) reviewed the literature looking for improved sub-models that could replace the simple linear model, and (3) developed sensitivity analysis to identify the more influential sub-models, to help suggest priorities in research to develop more accurate quantitative models, and (4) explored efficiencies in computation.

2.4 Second Iteration of the SDSS: 2009-2010

Based on multiple reviews of the data and results of the first iteration, the project partners made the following improvements in the second iteration (Table 1).

Table 1: System Improvements in the Second Iteration SDSS

Area	Improvement	Objective	Means
Threats data	Reviewed existing threats data. Presented results from first iteration and surveyed agency representatives to solicit best available datasets.	Motivate land managers and other stakeholders to provide better data.	Presentations, workshops, phone calls
	Derived data.	When no usable threat data are available, locate a proxy and/or develop threats data from contributing threat(s).	Use buffered weighted overlays of contributing threats

Area	Improvement	Objective	Means
Conceptual model	Threat > Threat > Stress > Population Effects > Population Change	Characterize risk as contributions to population change from all population effects. Standardize the model structure and terminology by basing it on a published lexicon. Extend population effects to include juvenile mortality, change in reproductive output and change in immigration/emigration rates.	Workshops and interviews. Add a new top layer to the weighted model.
	Recovery actions act on threat > stress mechanisms	More realistic models of how recovery actions function.	Change in the computational model
Computational model	Introduce area effects for threats contributing to stresses and other threats, and recovery actions.	Improve spatial accuracy of sub-models.	Add buffers to contributing threats and recovery actions
	Conduct custom designed weights survey.	Create online weights surveys that are designed to elicit weights on range-wide basis.	Online surveys, invited expert cohorts
Transparency	Create a Conceptual Model Manager tool to capture the network of how threats affect population change, weights and buffers.	Create an environment where scientists manage the conceptual model which in turn directs the system computations.	Create Web services that the main SDSS engine can access to obtain weights, buffers etc.

Source: Desert Tortoise SDSS, Second Iteration

The sections below highlight the system improvements in the second iteration that are most pertinent to the development of the third iteration of the system in the California Energy Commission project.

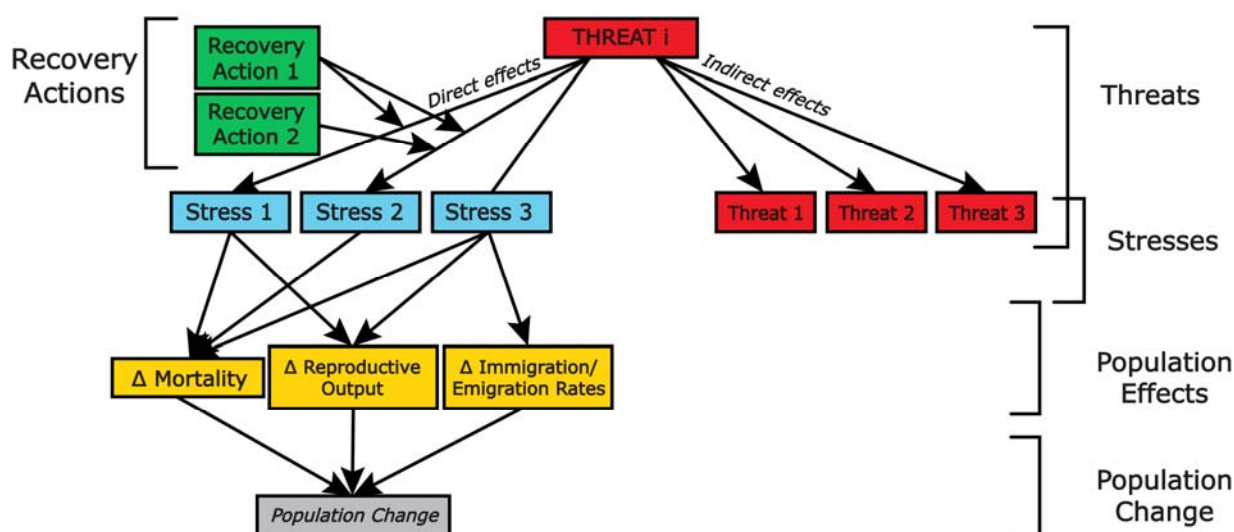
2.4.1 Conceptual Model Improvements

The second iteration of the system contained a new conceptual model that captures the most current and plausible hypotheses about how the complex network of threats and recovery actions affect desert tortoise populations, as recorded in Appendix A of the revised Recovery Plan (USFWS 2011). The project partners used a standard lexicon for biodiversity conservation (Salafsky et al. 2008), which defines and provides a list of potential threats, stresses, and conservation actions. This lexicon provides common elements that can be linked in a causal

chain to represent a hypothesis about how actions are expected to bring about desired outcomes.

For each threat, the project partners created an individual sub-model, and then connected the set of threat sub-models so that the combined direct and indirect effects of all threats to the species are captured in a single network (Darst et al. 2013; Figure 11). This network included population effects for two life stages (juvenile and adult) leading to four named population effects: change in adult mortality, change in juvenile mortality, change in reproductive output, and change in immigration/emigration. These population effects lead directly to changes in the tortoise population. (For definitions of terms used in the conceptual model framework, see Table 2 below, and Appendix A.)

Figure 11: Improved Conceptual Model Structure in the Second Iteration SDSS



This figure shows the new conceptual model framework implemented in the second iteration of the system. In contrast, the first iteration included only the contribution of threats to mortality mechanisms to mortality (Figures 3 and 4). In the second iteration conceptual model, all stresses, not just those that contribute to mortality, and the population effects beyond mortality, such as reproduction and immigration/emigration, were included.

Source: Darst et al. 2013

Linkages in the network indicate relationships that can potentially be affected by application of recovery actions. The new conceptual model structure made it possible to rank threats and prioritize recovery actions based on contributions to changes in *risk to the population*, where risk refers to overall population change from all possible population effects.

Table 2: Definitions of Key Terms in the Conceptual Model

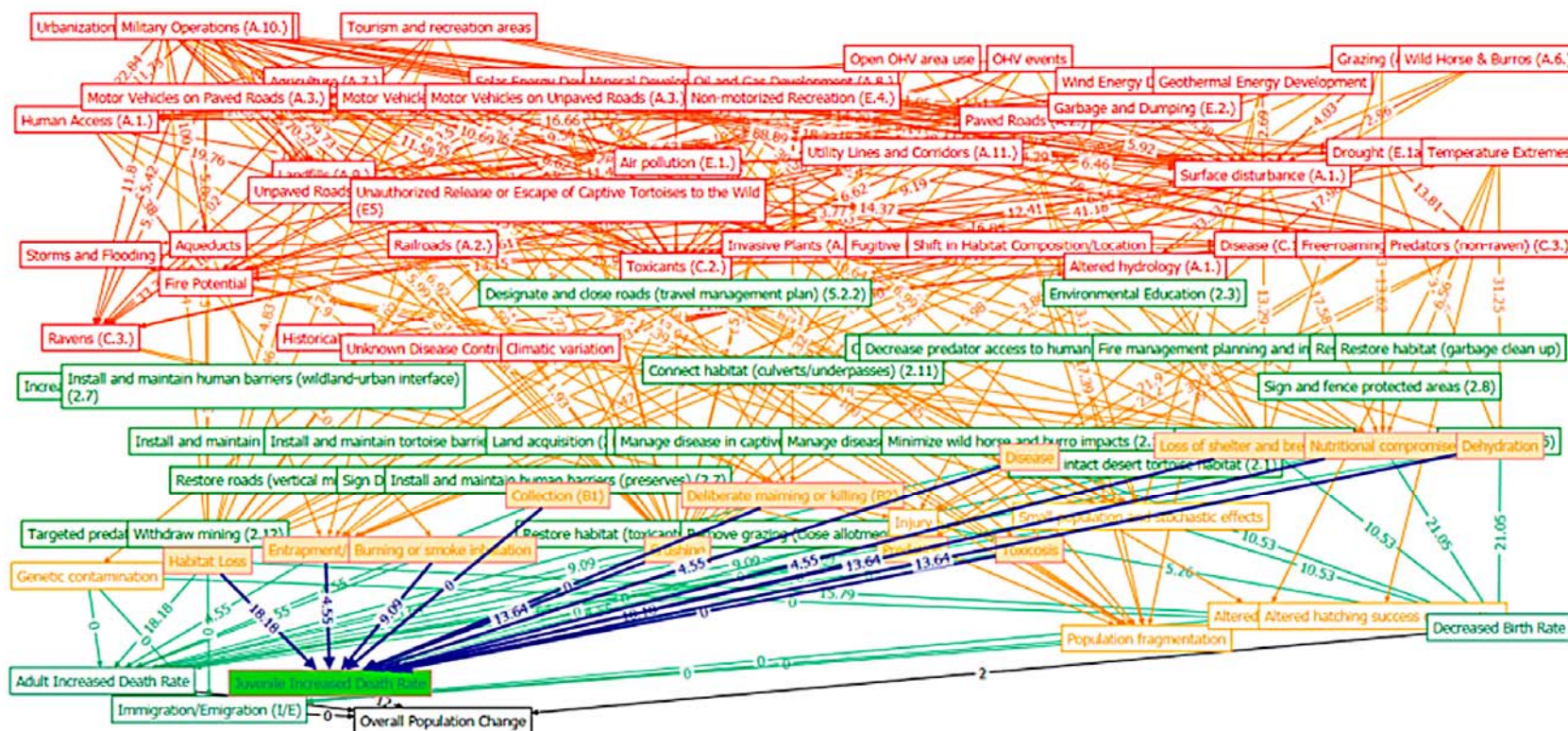
Term	Definition
Conceptual model	A representation of the set of causal relationships between factors that are believed to affect an at-risk species.
Conservation action	Interventions undertaken to reach conservation goals and objectives (Salafsky et al. 2008).

Term	Definition
Demographic rates	The combination of population effects (mortality, reproductive output and immigration/emigration) with tortoise life stages (juvenile and adult). The four demographic rates in the conceptual model are: change in adult mortality, change in juvenile mortality, change in reproductive output, and change in immigration/emigration.
Direct effects of a threat	Pathways from threats to stresses to associated population effects on population risk.
Generations of indirect effects	First generation: effects of threats that proximately result from the focal threat. Second generation: effects of threats that result from first generation threats are second-generation indirect effects, etc.
Indirect effects of a threat	Pathways to population risk that lead from a threat through resulting threats rather than directly through stresses.
Population effect	Change in mortality, reproductive output, or immigration/emigration in a population.
Recovery	The process by which the decline of an at-risk species is arrested or reversed so that its long-term survival in nature can be ensured.
Recovery action	Conservation actions that are designed specifically to contribute to the recovery of at-risk species.
Risk to the population	The contribution of threats, stresses, and demographic rates to the overall change in population that is occurring; for the desert tortoise, the absolute magnitude of that decline is unknown.
Stress	Degraded conditions or “symptoms” of the species that result from a threat (Salafsky et al. 2008).
Threat	Proximate human activities that have caused, are causing, or may cause the destruction, degradation or impairment of species (Salafsky et al. 2008).
Threats assessment	A systematic approach to assessing the relative importance of each threat to a species’ status.

Source: Table reproduced with minor modifications from Darst et al. 2013.

To capture this new conceptual model network, the project partners created an online tool called the Conceptual Model Manager. This tool is explained in detail in later chapters, but its core purpose is to integrate the conceptual model in its entirety, and provide a structure that the system can use directly for computations (Figure 12).

Figure 12: Conceptual Model Manager Tool Showing Extended Conceptual Model



The Conceptual Model Manager supports biologists in maintaining the conceptual model which relates threats (red) to stresses (light orange) to population effects (light green) to population change (black). Threats can also contribute to other threats indirectly (lines between red boxes). See Appendix A for a complete list of all entities shown, and their definitions.

Source: Desert Tortoise SDSS, Second Iteration: Conceptual Model Manager

2.4.2 Improvements in Weights Elicitation

The second iteration of the Desert Tortoise SDSS again used weighted contributions for all relationships in the model. Once the structure of the conceptual model was considered complete, the project partners created online surveys for two different groups of experts: (1) tortoise biologists with experience applying regulations to address how threats (such as “Urbanization,” “Solar Energy Development,” or “Paved Roads”) contribute to other threats (such as “Invasive Plants,” “Ravens,” or “Human Access”); and (2) tortoise biologists with experience and awareness of current research on mechanisms by which threats degrade conditions such as nutritional quality, extent of habitat loss, or predation rates specific to tortoises. These surveys elicited expert estimates of how changes in threats contribute to changes in other threats, and how changes in threats drive changes in stresses (Darst et al. 2013). The surveys asked the experts to think range-wide, rather than of specific locations. Each expert entered estimates of weights for all relationships in their survey. A mean weight was calculated after removing the highest and lowest values. The mean weights were then normalized to sum to 1, and entered into the Conceptual Model Manager. DTRO biologists estimated the relative contribution of stresses to each population effect, and of each population effect to population change based on the literature (see Darst et al. 2013 for more details).

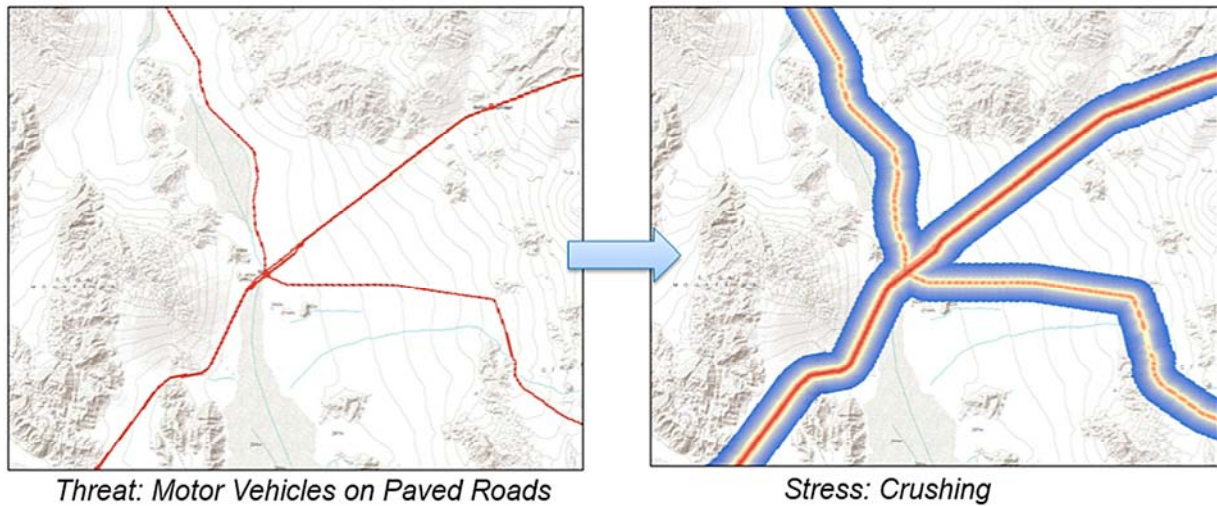
2.4.3 Improvements in Recovery Action Modeling

The revision of the conceptual model identified new threats, amalgamated others, and eliminated some threats. In addition, the interaction of recovery actions with threats was modeled differently in the second iteration. Instead of reducing an affected threat, recovery actions were modeled as reducing the mechanism by which a threat affects the population (the threat-to-stress link in the model; Darst et al. 2013). In many cases, it is not the threat *per se* that can be ameliorated with a recovery action; rather, it is the stress caused by the threat. For example, tortoises are crushed by cars on paved roads. The threat is the cars; the effect of that threat, or the stress, is tortoises being crushed. The recovery action of “Install and Maintain Tortoise Barrier Fencing” along the road does not reduce the threat (i.e., car traffic or “Motor Vehicles on Paved Roads”), but it does reduce the effect of the threat (i.e., tortoises being crushed by cars on the road, or “Crushing”).

2.4.4 More Realistic Spatial Models

A threat may be localized, but its impacts, whether contributing to other threats or directly to stresses, may cover a larger area. For example, collisions of tortoises with “Motor Vehicles on Paved Roads” results in an increase in the stress of “Crushing” in the population a few kilometers on both side of the roads (Figure 13). Another example is a mine, which has a localized footprint, but can contribute to the threat of “Fugitive Dust” over a larger area. The second iteration of the Desert Tortoise SDSS accommodated this extended area of impact. Based on the literature, the project partners assigned buffers to those contributing links where such an *ecological effects area* applied. No such extended effects were introduced for stresses contributing to population effects, or for population effects contributing to population change. Incorporating ecological effects areas required a new step in the spatial calculations, in which the system generated a normalized threat ecological effects layer where applicable (Figure 14).

Figure 13: Example of Ecological Effects Layer

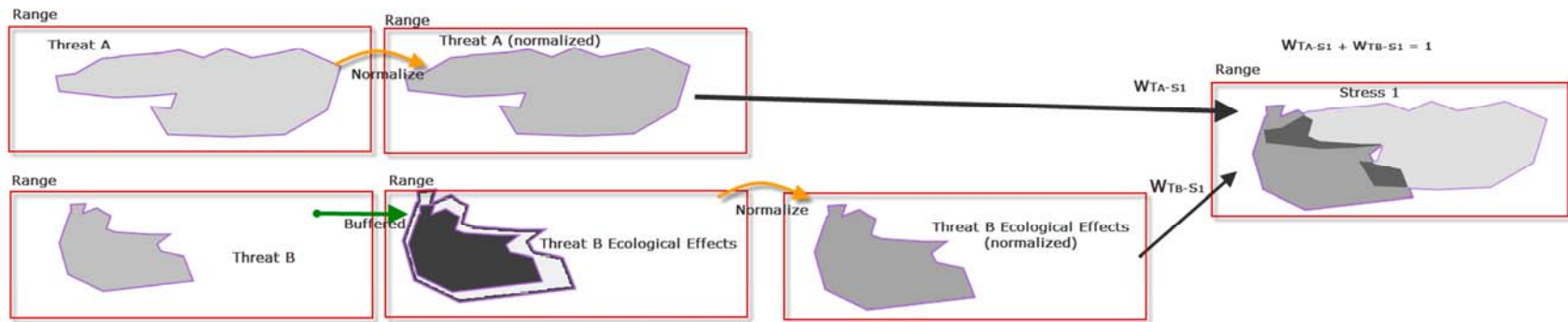


The threat of "Motor Vehicles on Paved Roads" contributes to the stress of "Crushing" with a threat effects area of 3km on each side of the road. The intensity of the contributions depends on the road classification: more heavily used roads contribute more to the overall threat intensity.

Source: Desert Tortoise SDSS, First Iteration

Some recovery actions may also have an effects area beyond where they are implemented. For example, roadside tortoise fencing can benefit populations up to a few kilometers from the road (Boarman and Sazaki 2006). Although the recovery action occurs on the side of the road, its effects area extends for several kilometers to benefit the population on both sides of the road.

Figure 14: Spatial Calculation of Stress Layer Incorporating a Normalized Ecological Effects Area Layer



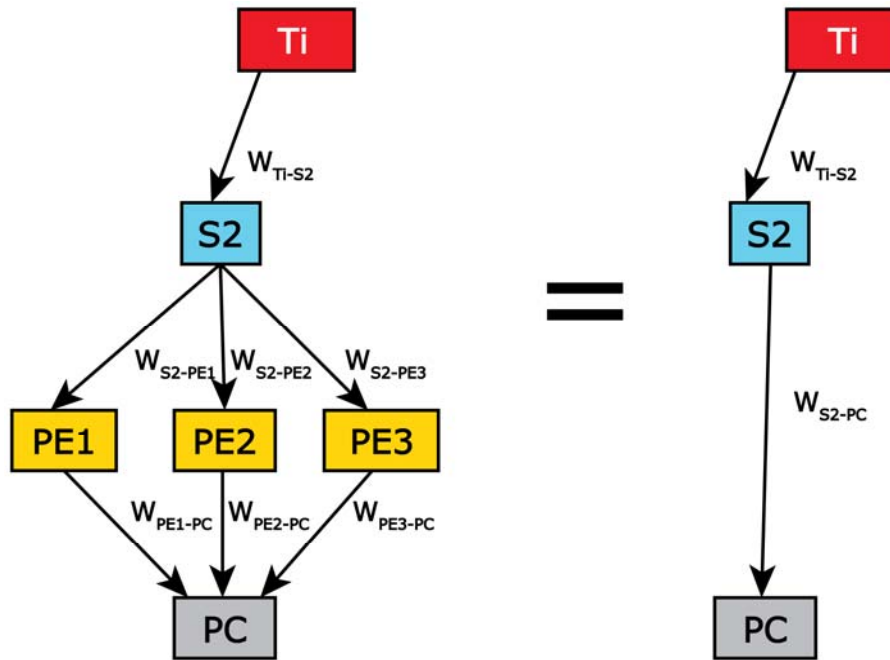
Calculating Stress 1 from contributing Threats A (T_A) and B (T_B). Threat B has an ecological effects area greater than its intensity footprint.

Source: Desert Tortoise SDSS, Second Iteration

2.4.5 Direct Weights of a Stress to Population Change

Because a threat may have an ecological effects area when it contributes to a specific stress, the aspatial algebraic derivation of the *direct weight* described in the first iteration (Section 2.2.2) could no longer be used. Instead, the project partners created spatial stress layers as in Figure 14, and then calculated a *direct stress weight* representing the contribution of a stress to population change (Figure 15). The direct stress weight summed the products of individual weights along the paths that linked that stress to population effects, and the population effects to population change.

Figure 15: Calculation for a Direct Stress Weight from Individual Linked Weights



$$W_{S2-PC} = (W_{S2-PE1} * W_{PE1-PC}) + (W_{S2-PE2} * W_{PE2-PC}) + W_{S2-PE3} * W_{PE3-PC})$$

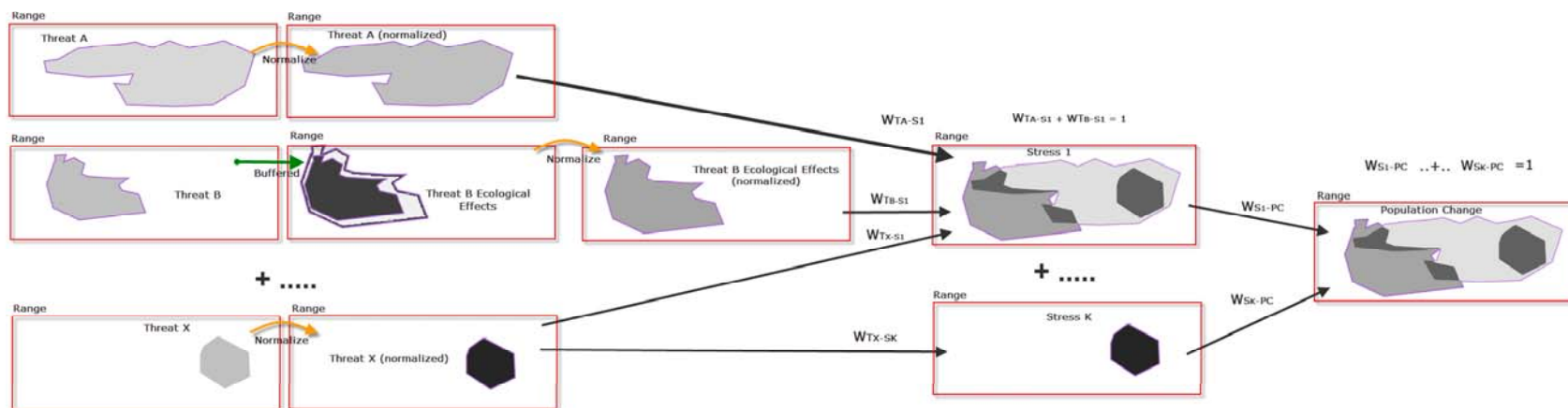
The direct stress weight W_{S2-PC} is the sum of the product of all weights along each path from the Stress S_2 to population change. In this example there are three such paths.

Source: Desert Tortoise SDSS, Second Iteration

2.4.6 Spatial Computation of Risk

The system estimates risk as the contribution to population change at every point within the range. Each stress layer is multiplied by the direct stress weight and all values are summed to arrive at the contribution to population change at each point on the map (Figure 16). This approach does not estimate the *absolute* change in population, but rather the *relative* contribution of threats or stresses to whatever population change is occurring, and thus the contribution to an increase in risk to the population. *Relative* contribution means that, instead of being able to state that the threat “Toxicosis” accounts for X% of adult mortality (the *absolute* mortality), the system is limited to calculating its contribution to whatever population change is occurring relative to other threats.

Figure 16: Spatial Calculation of Risk to Population from Threat Intensity Layers



Source: Desert Tortoise SDSS, Second Iteration

2.4.7 Summary of Calculation in the Second Iteration

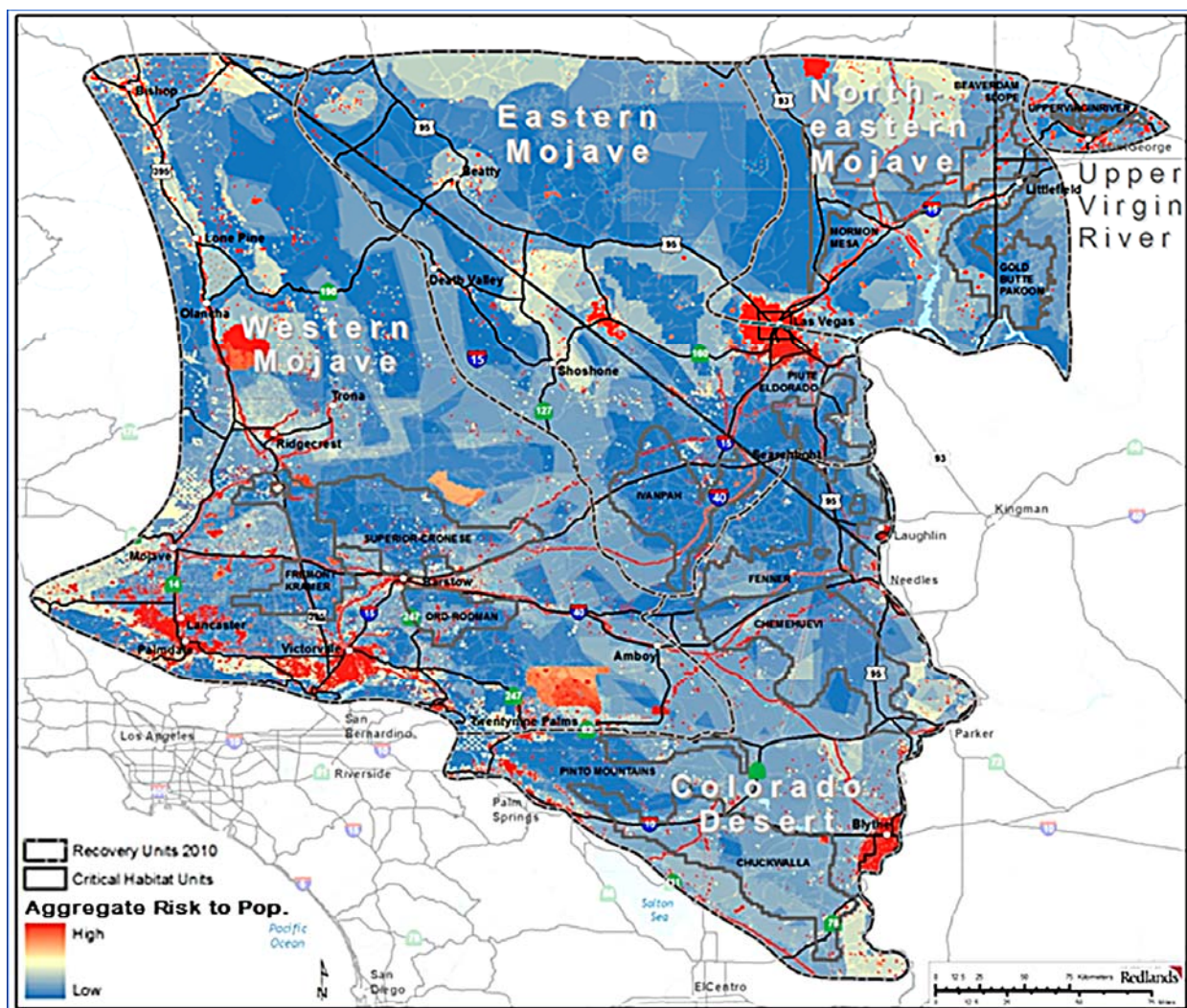
To summarize, the computational approach for the second iteration of the Desert Tortoise SDSS was:

- (1) Acquire spatial maps of the intensity of identified threats.
- (2) Normalize each individual threat layer across the range, to create a normalized threat layer.
- (3) If the footprint of the effect of the threat is different than the threat itself, apply the appropriate buffers to produce the ecological effects area layer, and spatially normalize the resulting layer.
- (4) Multiply each normalized threat or threat ecological effects layer by the threat-to-stress weight, and sum the weighted layers across the range to estimate the resulting stress layer.
- (5) Multiply each stress layer by its direct stress weight, then sum all the contributions to population change at every point to estimate the spatially-explicit contribution to an increase in risk to the population.
- (6) Either assume a recovery action would be implemented rangewide or obtain footprints for where recovery actions would be implemented, and buffer to their effective extent if applicable.
- (7) Where recovery actions and the affected threats overlap, reduce the contribution of those threats to population change by the effectiveness recovery action weight, resulting in a map of reduced aggregate risk to the population.
- (8) Compare, spatially and numerically, reductions in risk to the population due to the individual site specific recovery actions to determine which recovery actions may be most effective.

2.4.8 Results for the Second Iteration

With a more complete conceptual model, higher quality spatial maps of the intensity of identified threats, and updated spatial modeling, aggregate risk to the population maps with much less obvious artifacts were produced (Figure 17). The project partners re-ran scenarios where each recovery action was implemented range-wide (Figure 18), and estimated the effectiveness for suites of recovery actions, breaking down the aggregate results by stresses or by threat (Figure 19).

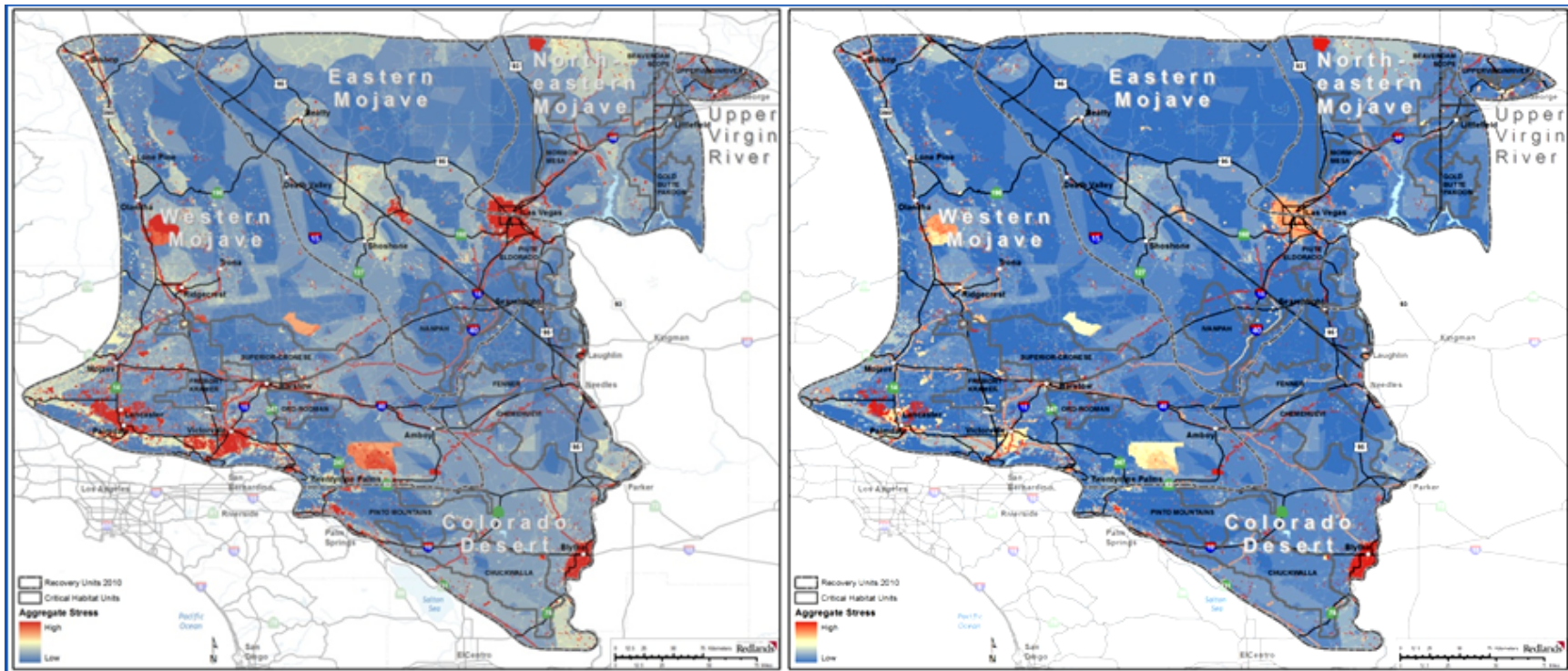
Figure 17: Aggregate Risk to the Population in the Second Iteration SDSS



Output aggregate risk to the population from the second iteration of the Desert Tortoise SDSS. Areas in red show higher risk to the tortoise population; areas in blue show lower risk.

Source: Desert Tortoise SDSS, Second Iteration

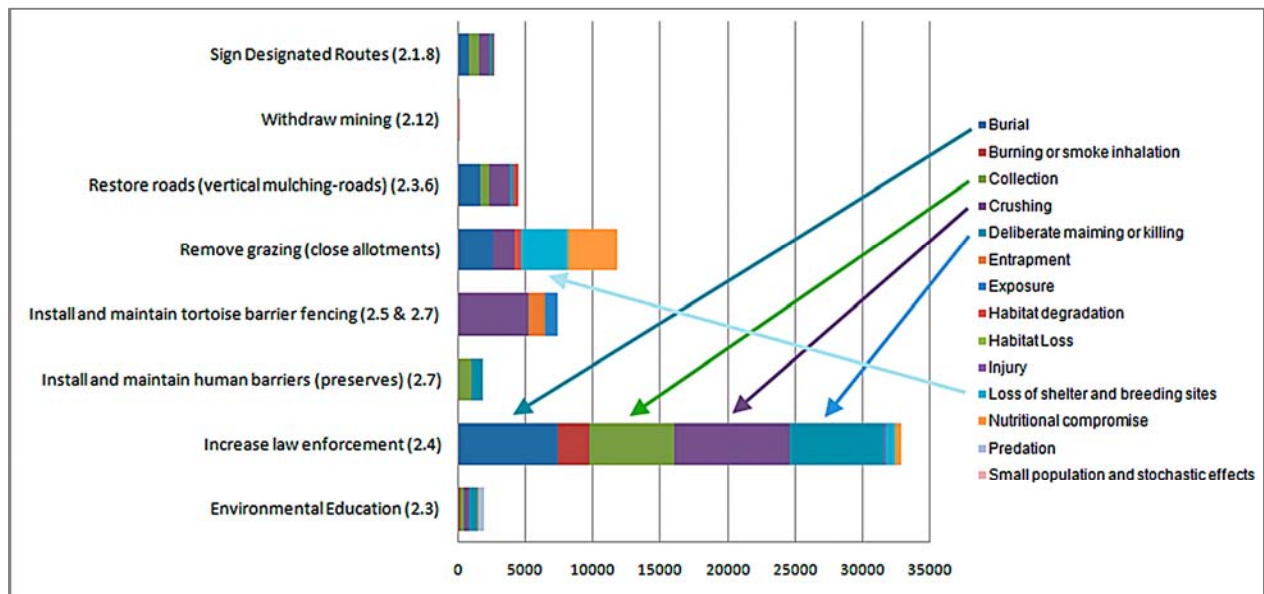
Figure 18: Map of Change in Risk to the Population



Map of risk to the tortoise population before and after the hypothetical recovery action of “Targeted Predator Control” across the entire range. Areas in red show higher risk to the tortoise population; areas in blue show lower risk.

Source: Desert Tortoise SDSS, Second Iteration

Figure 19: Results for a Suite of Site-specific Recovery Actions in the Western Mojave, Using the Second Iteration SDSS



Aggregate reduction in risk to population due to a suite of site-specific recovery actions (for the Western Mojave), broken down by reduction in population stresses. For example, physically blocking boundaries around designated preserves (the recovery action of “Install and Maintain Human Barriers”) would reduce the stresses of “Collection” and “Deliberate Maiming or Killing.”

Source: Desert Tortoise SDSS, Second Iteration

On completing the second iteration, the project partners were confident in the system’s ability to calculate impacts and recovery actions related to existing threats to the desert tortoise. The project team also perceived future enhancements that would improve the speed and accuracy of system calculations, for example:

- The calculation could be speeded up. Spatial calculations of risk to the population could take up to 36 hours in the second iteration of the Desert Tortoise SDSS. This precluded more spatially-explicit calculations.
- Some recovery actions required much smaller spatial scales. For example, tortoise fencing needed to be analyzed on scales of 100m, not the kilometer scales of the second iteration.
- A proxy for range-wide tortoise density is needed to deal with the continued assumption in the second iteration that tortoise population density is equal across the range.
- In addition to handling existing threats, the system could be adapted to evaluate new threats to the landscape and their corresponding impacts in the model.
- The system has the potential to calculate changes in risk to the population from threats (increased risk) and from recovery actions (decreased risk) on a common scale, which would allow for the representations of potential suites of recovery actions for mitigation.

- Increasing focus on solar energy development in the Mojave, as evidenced by the increase in permitting applications, represented the most current and pressing threat to recovery of the desert tortoise. As the desert tortoise is the primary species of concern in the Mojave, improving the system's ability to calculate threats from these new solar energy development projects would be a timely and valuable application of the system.

These findings led the project team to submit a proposal to the California Energy Commission to expand Desert Tortoise SDSS models and technology to calculate the combined impacts of solar energy development projects on the desert tortoise and the relative benefits of recovery actions.

CHAPTER 3:

SDSS Conceptual and Computational Models

Chapter 2 provided an overview of the iterative development of the Desert Tortoise SDSS in 2007-2010, prior to California Energy Commission funding. Chapter 4 describes specific actions taken by the partners during the Energy Commission project to extend the underlying models and improve system components, processing and computation to:

- Estimate the increase in risk to the desert tortoise population resulting from modeled implementation of proposed solar energy development projects.
- Calculate the decrease in risk to the tortoise population resulting from modeled implementation of recovery actions which could be conducted as mitigation.

This transitional chapter describes some fundamental elements and differences in calculations between the pre-existing Desert Tortoise SDSS and the extensions made as part of the Energy Commission project. The sections below describe in more detail the *conceptual* and *computational models* as implemented in the third iteration of the system, and in particular, changes in the conceptual model and computations relating to the addition of new threats (e.g., proposed solar energy development projects) to the landscape.

3.1 The Core Models in the Third Iteration of the SDSS

In the Desert Tortoise SDSS, the *conceptual model* is the information hub of the system and describes the complex interrelationships of threats to the population, the stresses that are the response of the population to those threats, the population effects that are affected by those stresses, and the recovery actions that may reduce effects of threats (Darst et al. 2013). The *computational models* implement aspatial and spatial (geoprocessing) analysis calculations based on the knowledge and data defined in the conceptual model.

As the project team moved towards a more comprehensive population change model in the second and third iterations of the system, new sub-models were created and/or expanded within the conceptual model. The third iteration includes the following sub-models within the Desert Tortoise SDSS conceptual model:

Threat-based population change models

- *Threat-to-Threat Interaction Model*: estimates the contribution of a (focal) threat to another threat. For example, the threat of “Invasive Plants” contributes to the threat of “Fire Potential.”
- *Threat-to-Stress Interaction Model*: estimates contribution of each threat to population stress. For example, the threat “Invasive Plants” contributes to the stress of “Nutritional Compromise.”
- *Relative Stress Model*: estimates contribution of each stress to population effects. For example, the stress of “Nutritional Compromise” contributes to a change in the

population effects of “Change in Mortality (Adult)” and “Change in Reproductive Output.”

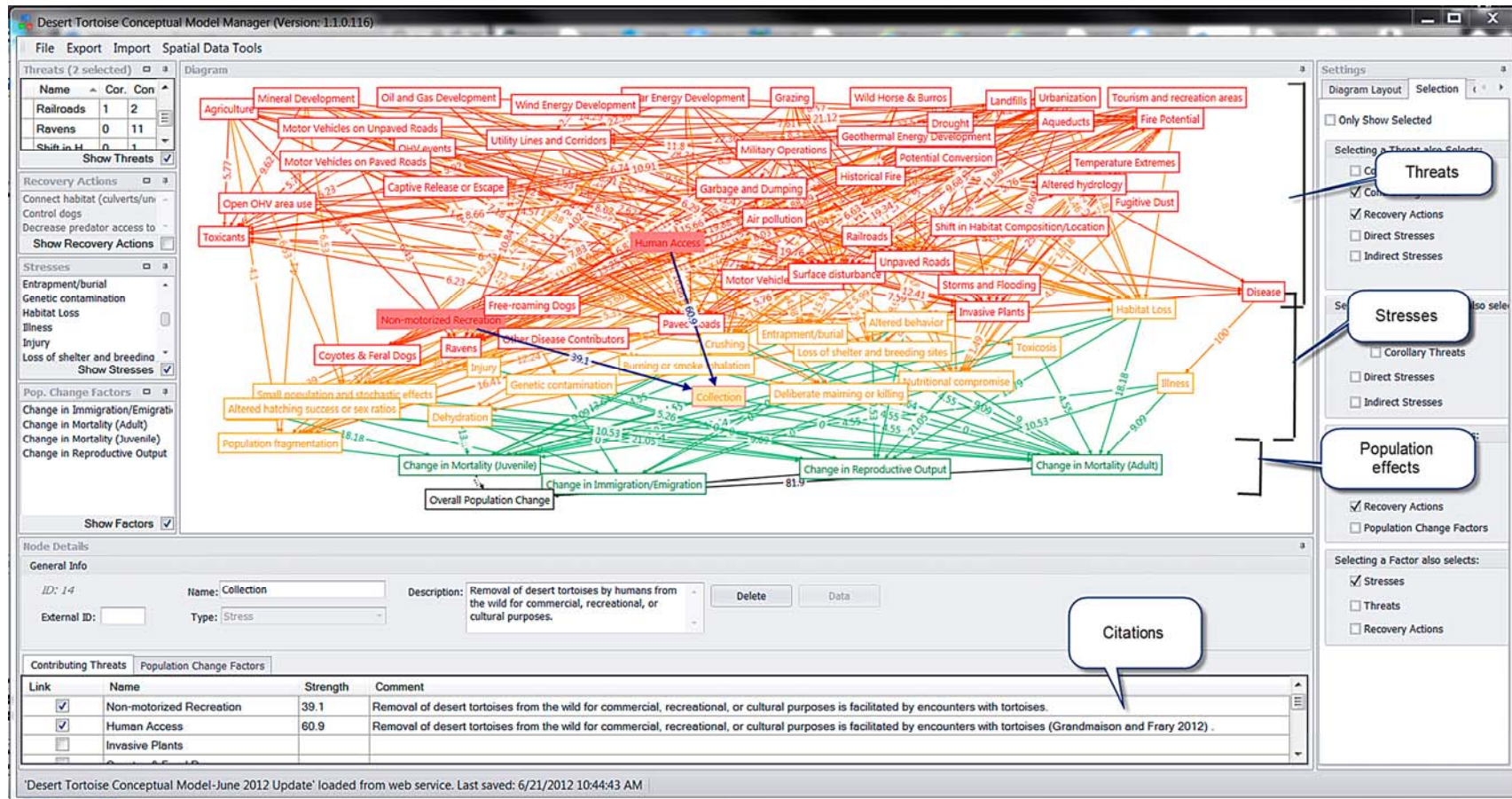
- *Demographic Impact Model*: estimates contributions of population effects to overall population change.

Recovery action threat-to-stress suppression models:

- *Threat-to-Stress Mechanism model*: threats cause stresses in the population via a mechanism. For example, the threat of “Motor Vehicles on Paved Roads” causes the stress of “Crushing” through the mechanism of “On-road Collisions.”
- *Recovery Action Effectiveness model*: estimates the amount of a threat-stress mechanism that the implementation of a recovery action suppresses. For example, the recovery action of “Install and Maintain Tortoise Barrier Fencing” along both sides of a road prevents tortoises from getting on to the road, and so removes the danger of “On-road Collisions.”

All of these conceptual relationships are captured, managed and described using the Conceptual Model Manager tool piloted in the second iteration and improved during this third iteration (Figure 20). Biologists can enter strengths of the model linkages (interactions) and cite the literature that provides evidence for each relationship.

Figure 20: Improved Conceptual Model Manager Tool in the Third Iteration SDSS



The Conceptual Model Manager displays a representation of the threats-based desert tortoise conceptual model (here in the third iteration SDSS). The user interface for managing and visualizing the components and knowledge contained in the conceptual model was greatly improved during the third iteration of system development.

Source: Desert Tortoise SDSS, Third Iteration

The third iteration of the Desert Tortoise SDSS employs the following spatial *computational* sub-models, which were also modified during this project and will be described in detail in the next section.

Spatial Threats Model: uses geospatial data to represent where and with what intensity threats occur geographically.

Models of the risk to the tortoise population on the ground

- *Spatial Threats-based Population Change Model:* combines spatial data with stress to population models to estimate risk to the population from the combined (direct and indirect) effects of all threats.
- *Risk to Population Model:* weights the contribution of threats to population change by the probability of whether a tortoise is likely to occur at that location on the landscape. The acquisition and use of a *probability of presence* layer is described in Section 3.3.

Pre-action Aggregate Risk Model: estimates risk to the population by all threats and stresses, weighted by probability of presence.

Recovery Action Effectiveness Model: estimates effectiveness of recovery actions in reducing threat-to-stress links; then combines estimated risk to the population with recovery action effectiveness to estimate change in risk to the tortoise population as a result of implementing a site-specific recovery action.

3.2 Calculating Change in Population Risk Due to Threat Increases

The first two iterations of the Desert Tortoise SDSS were designed to assess the aggregate risk to the tortoise population from *existing* threats and estimate the effects of recovery actions at ameliorating those threats. Subsequently, the project team realized that the system could be extended to calculate the increase in risk to the population from *new* and/or increases in threats: for example, those additional threats which might result from the implementation of a utility-scale solar development project in tortoise habitat.

The rest of this chapter describes in detail how the system handles the calculation of increases in risk to the population, due to the introduction of new threats on the landscape. Each threat in the model contributes to an increase in risk to the population directly through stresses, and indirectly from contributions to other threats. Thus, the overall contribution of a threat to increase in risk is the sum of the contributions of both direct and indirect effects (Darst et al. 2013). This is true for the assessment of existing threats on the landscape; it is also true for new, proposed threats on the landscape.

3.2.1 Direct Effects of a New Threat

Suppose that Threat A (for example, a new solar energy development project) appears in a new location on the landscape. This is represented as an addition to the existing threat intensity layer (described in Section 2.2.3), and the intensity values of this new addition must be in the same units as the original threat map. In fact, the spatial calculation to estimate the increase in a stress

that the new threat contributes directly to (for example, “Habitat Loss”), is similar to that described in Section 2.4.5. The normalization of the now expanded Threat A does not change, as this additional area of threat did not exist when the experts estimated the contribution of Threat A to stresses and other threats.

In the third iteration, the system first multiplies the additional area of Threat A by the original normalization factor, then multiplies by the direct stress weight for Threat A, and finally adds the additional area to the original stress layer (Figure 21). For example, if Threat A (T_A) contributes with a weight W_{TA-S1} to Stress 1, and Threat A does not have an expanded ecological effects layer when contributing to Stress 1, then the system calculates the increase in Stress 1 by:

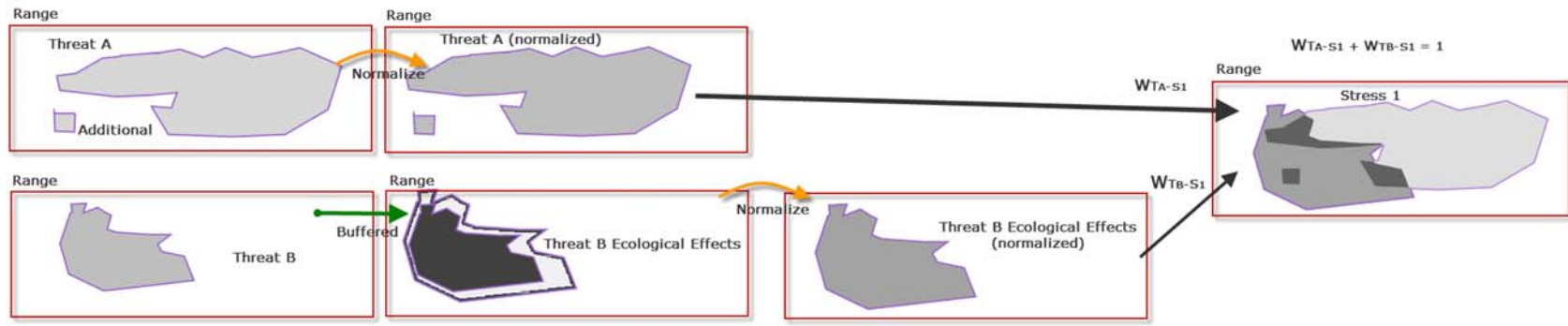
- (1) Multiplying the additional area of Threat A by the original normalization factor.
- (2) Multiplying this normalized additional Threat A footprint by W_{TA-S1} .
- (3) Adding the normalized and weighted additional area to the original calculated stress layer.

If Threat B, which does have an expanded ecological effects area, appears in a new location, the original normalization factor for the ecological effects layer of Threat B is still appropriate. The system then calculates the increase in Stress 1 in a similar way as in Section 2.4.5 (Figure 22):

- (1) Applying the buffers that generate the ecological effects layer for Threat B to the additional area of the threat.
- (2) Multiplying this additional, expanded area by the original normalization factor for Threat B’s ecological effects layer.
- (3) Multiplying this normalized additional ecological affects by W_{TB-S1} .
- (4) Adding the weighted, normalized additional area to the original calculated stress layer.

Similar calculations would be done for all stresses to which the increased threat contributes directly.

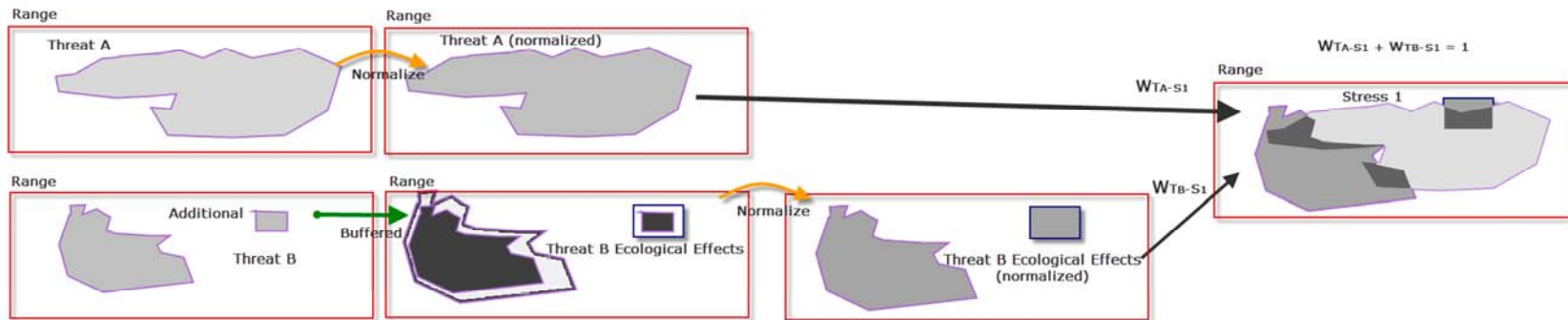
Figure 21: Spatial Calculation of Increase in a Stress Due to a New Area of Threat



Calculating the increase in Stress 1 due to the addition of a new area of Threat A, where Threat A has no expanded ecological effects area (area affected is not larger than the threat footprint) when contributing to Stress 1.

Source: Desert Tortoise SDSS, Third Iteration

Figure 22: Calculation of Increase in a Stress Due to a New Area of Threat with an Expanded Ecological Effects Area.



Calculating the increase in Stress 1 due to the addition of a new area of Threat B, where Threat B has an expanded ecological effects area (area affected is larger than the Threat footprint) when contributing to Stress 1.

Source: Desert Tortoise SDSS, Third Iteration

3.2.2 Indirect Effects of a New Threat

To calculate the indirect effects of the addition of a new threat, consider a situation where an increase in one threat contributes to increases in another threat. Suppose Threat A also contributes to Threat X: for example, an increase in “Surface Disturbance” leading to an increase in “Fugitive Dust.” The system calculates the increase in Threat X due to the increase in Threat A in a similar manner to the increases in stress just described, but with two differences:

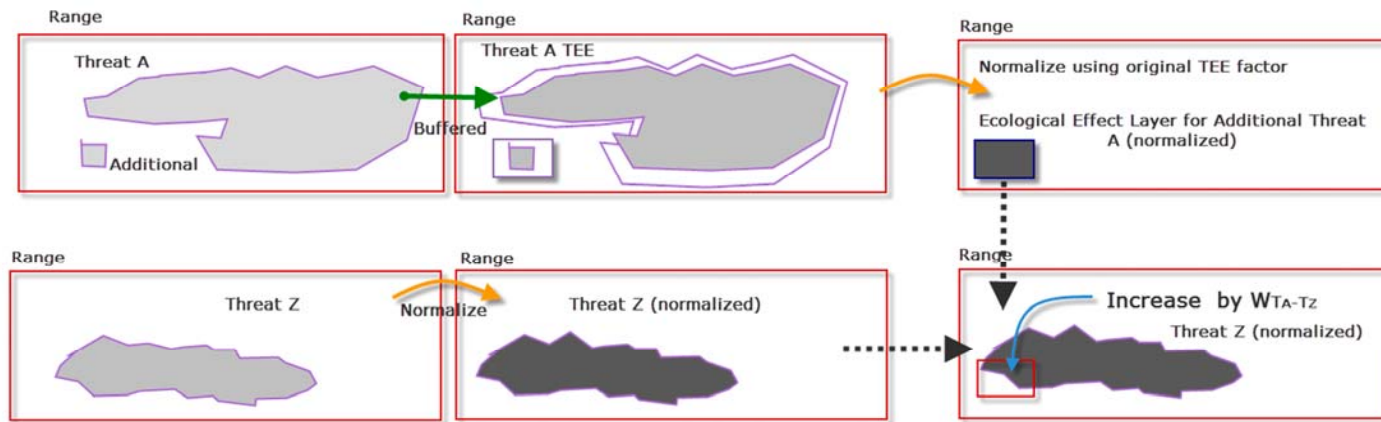
- (1) The spatial extent of indirect effects may not be the same as the threat itself.
- (2) Threats that arise from an originating threat may have cascading indirect effects of their own, creating *generations of indirect effects* (Darst et al. 2013). Threats that proximately result from the focal threat are the first-generation indirect effects of that focal threat. Threats that are indirect effects of the first-generation threats are the second-generation of indirect effects of the focal threat, and so on.

Regarding the first key difference: the footprint of the indirect effects are not necessarily the footprint of the threat itself. For example, when the system calculates an increase in Threat X (e.g., “Paved Roads”) due to an increase in Threat A (e.g., “Solar Energy Development”), the footprint of the increase in roads may be outside the footprint of the new energy development. Therefore, to calculate the indirect effects, the system uses a spatial change model. The spatial change model can follow one of two patterns: (1) increase intensity in existing threat layer (more traffic on existing road) within an ecological effects area; or (2) adding additional elements to the existing threat (e.g., a new road associated with an energy development project; Figure 23).

When new elements are added to an existing threat layer, the project partners ask energy project developers and analysts where and how much that change would be. For example, when an energy development project is proposed in the desert, it often needs an access road(s). While the conceptual model links an increase in energy development to an increase in roads, it does not have a model to suggest *where* that new feature(s) will be located on the landscape. Instead, the layout of proposed access roads is included as part of the proposal, supplying information about where the change in that threat likely will occur (Figure 24).

The second key difference between threat-to-threat calculations and the direct threat-to-stress calculations, is that an increase in one initial, *focal* threat can increase another threat, which may in turn increase any threats it contributes to, and so on. So in theory, an infinite number of cascading generations of threat increases could occur from the addition of any new threat (Figure 25).

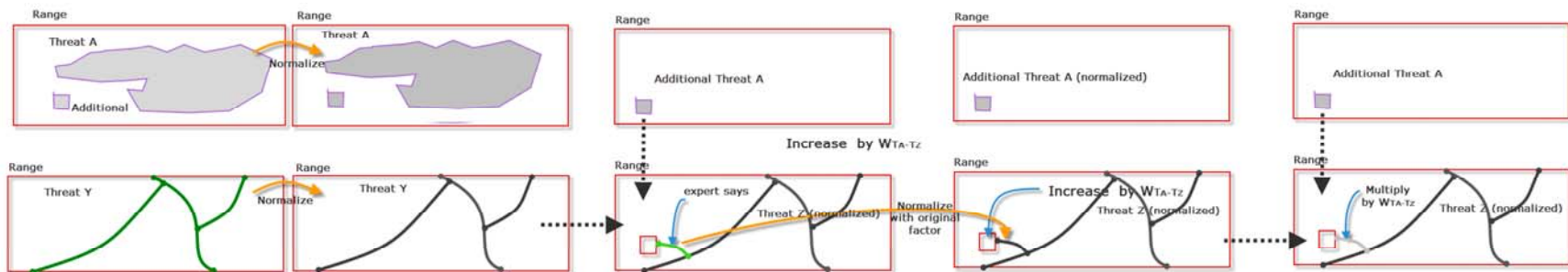
Figure 23: Calculation of Increase in Threat Due to Indirect Effects of a New Threat



Increase in intensity of existing Threat Z due to increase in Threat A. Threat A has an expanded ecological effects area when contributing to Threat Z. That area is generated for the addition to Threat Z, and those areas of Threat Z that overlap with Threat A's expanded effects area have their intensity increased by W_{TA-TZ} . If Threat Z itself contributes to another Threat, a similar calculation would be executed for that link, and so on.

Source: Desert Tortoise SDSS, Third Iteration

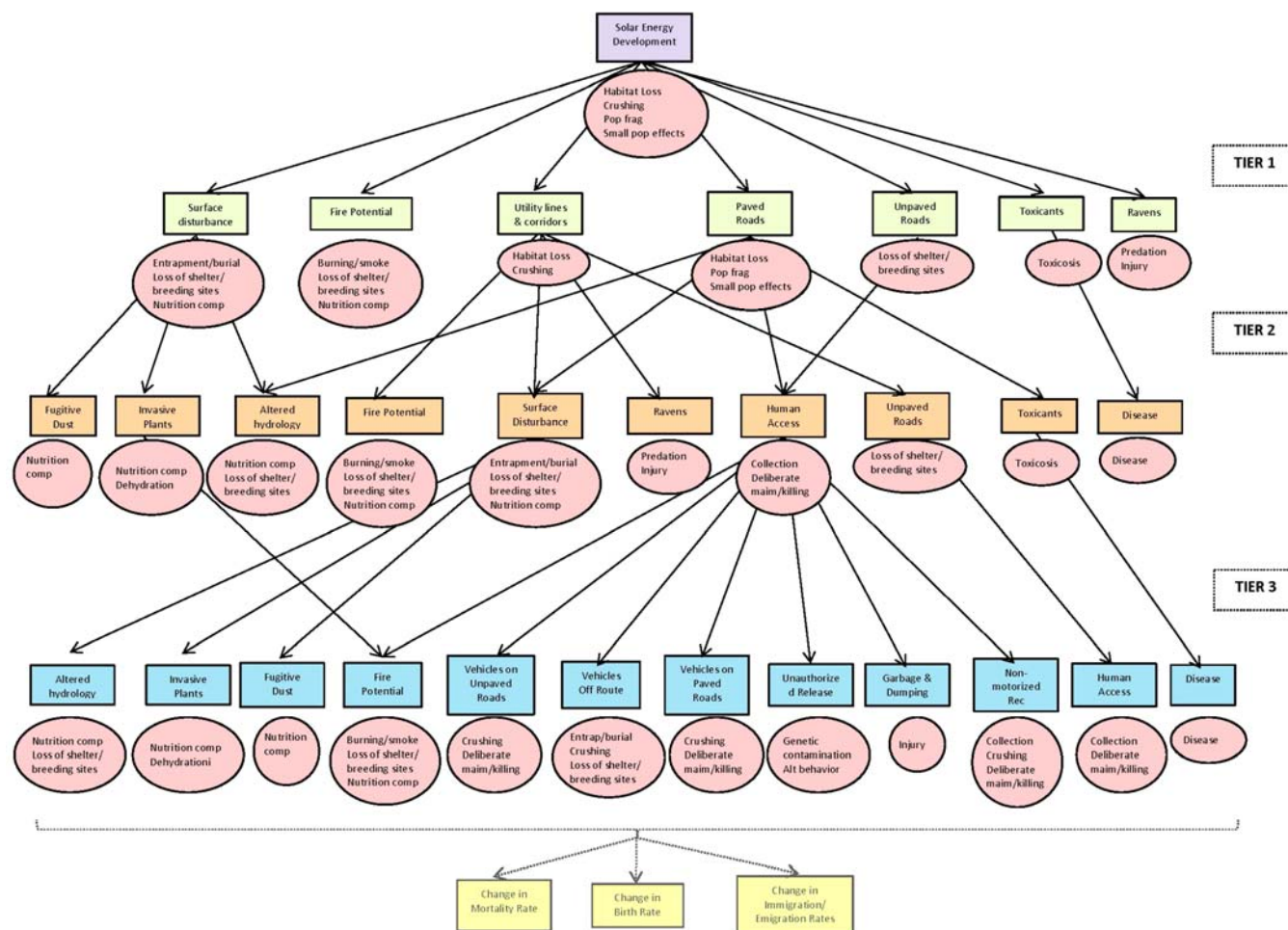
Figure 24: Calculation Including Expert Provided Information about Where the Change in an Indirect Threat Will Likely Occur



Additional elements added to Threat Y due to the increase in Threat A that contributes to Threat Y. The people working on developing or analyzing a project provide the information about where new elements would be created. The new elements are normalized using the original normalization factor for Threat Y, then its intensity scaled by the contribution weight W_{TA-TY} . If Threat Y itself contributes to another Threat, a similar calculation would be executed for that link, and so on.

Source: Desert Tortoise SDSS, Third Iteration

Figure 25: Example of Cascading Generations of Threat Increases from a Focal Threat



The cascade for 3 generations (tiers) of threats that the addition of a solar energy development project could produce, according to the links in the conceptual model. Rectangles indicate threats, and ovals indicate stresses.

Source: Desert Tortoise SDSS, Second Iteration

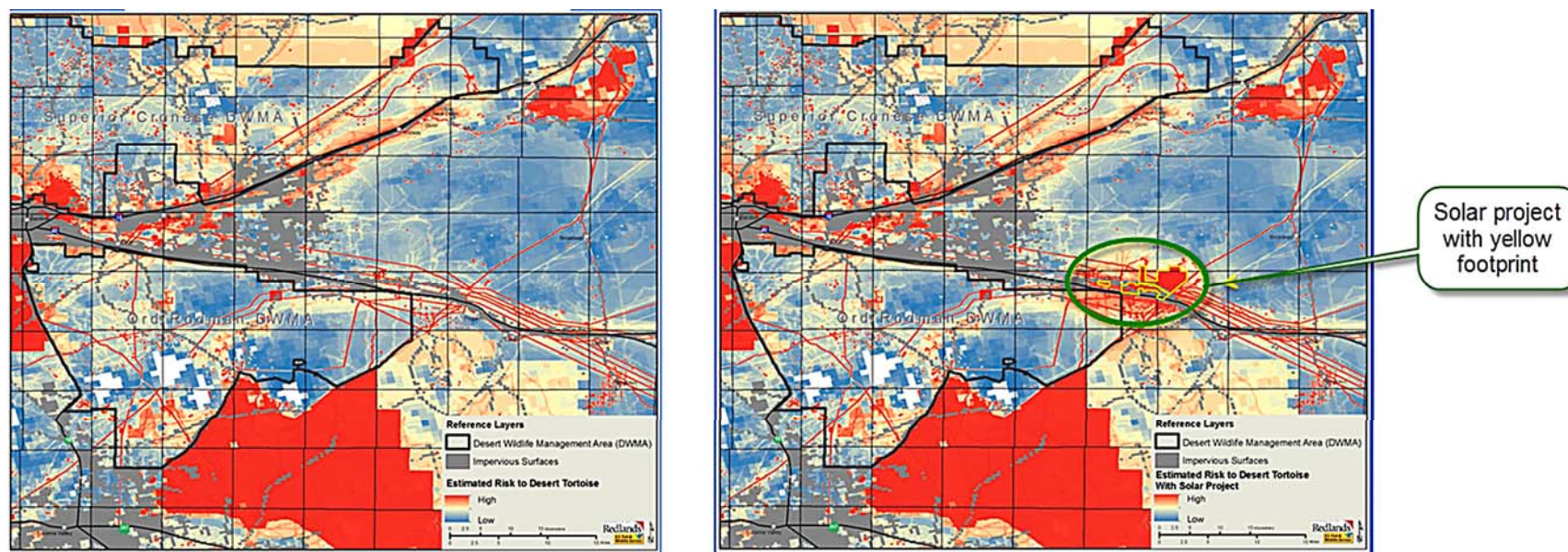
Regardless of which spatial threat-to-threat case is involved, the increase to the next threat always involves multiplying by the threat-to-threat weight. Because all linkage weights are < 1 , products of weights describe a proportionally smaller indirect effect as subsequent generations of effects are examined (Darst et al. 2013). The number of indirect pathways that need to be included in the calculation can be capped by following every threat-to-threat path from the focal threat, adding generations of indirect effects until either all indirect effects that result from a threat were included, or the inclusion of an additional generation resulted in a contribution ≤ 0.01 percent of the threat (which usually happens within five generations).

This aspatial determination of all pathways that need to be considered is computationally fast. In this project, a complete list of significant aspatially derived pathways was used to guide the full spatial calculation. The Desert Tortoise SDSS executes each path from the list in full: starting with the source threat layer addition, it executes the spatial threat-to-threat calculations described above for each threat-to-threat link in the model until it calculates the spatial increase to the stress layer at the end of the path.

3.2.3 Calculating Change in Relative Risk to the Population

To calculate the overall increase in population change due to the increase in the focal threat layer, the increases in stresses from both direct and indirect effects of the focal threat are multiplied by the direct stress weight and the resulting layers are summed to create a layer showing the increase in the risk to population (Figure 26).

Figure 26: Calculation of Increased Risk to Tortoise Population from a Proposed Solar Energy Project



Calculation is from an actual proposed solar energy development project. The image on the left shows a baseline map of the risk to population in the Western Mojave; the image on the right shows the estimated increase in risk, were a specific solar energy project to be sited where shown. Red areas indicate areas of higher risk.

Source: Desert Tortoise SDSS, Third Iteration

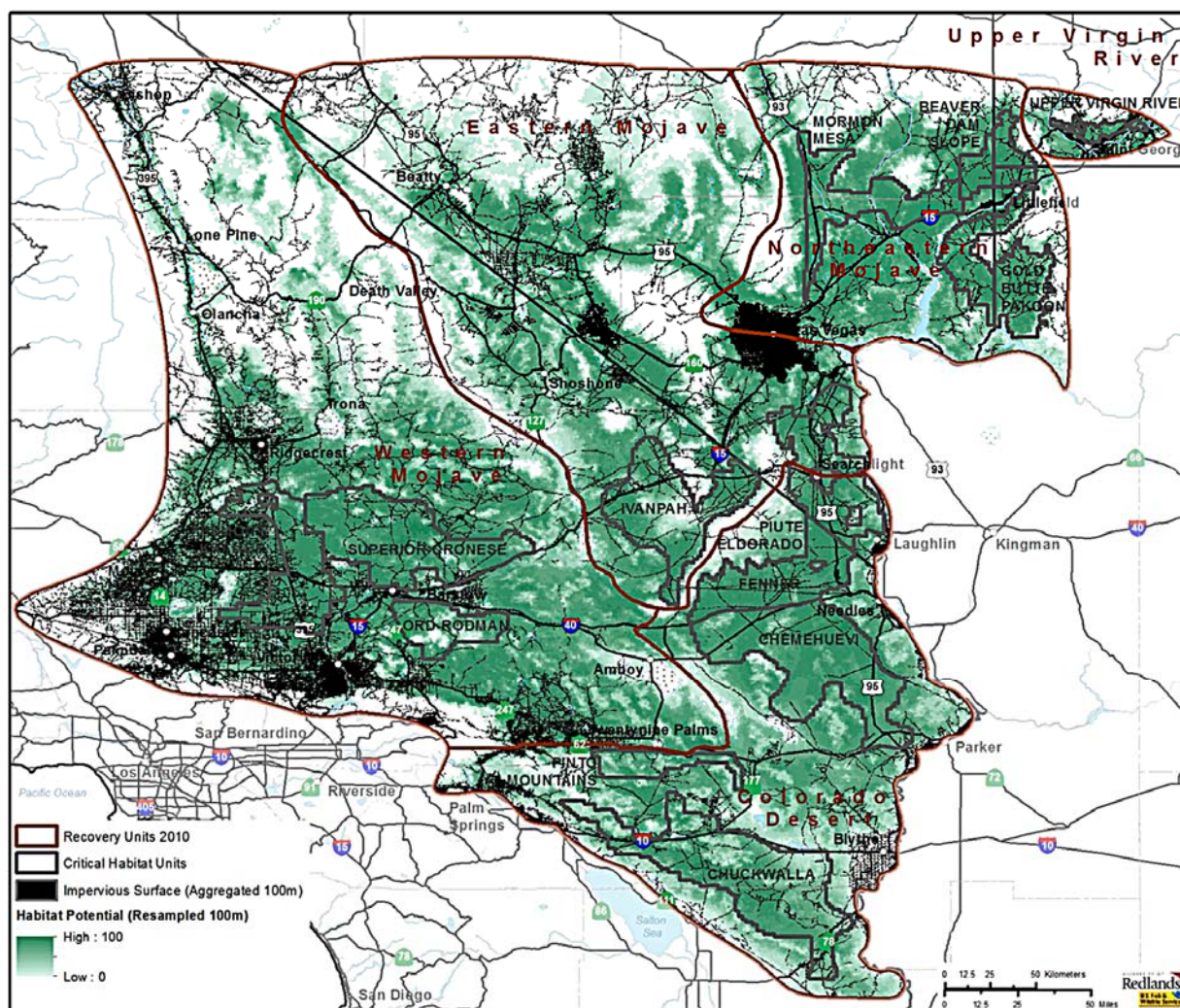
3.3 A Common Scale for Risk

3.3.1 Probability of Presence

The first iterations of the Desert Tortoise SDSS modeled where threats to the tortoise currently exist, and estimated risk to the population operating under the assumption that tortoises are equally distributed across the landscape. To address this assumption, and in the absence of an observed range-wide population density surface, the third iteration of the system incorporated the heterogeneous distribution of tortoises into the risk calculation by including the *probability of presence* for the desert tortoise.

To estimate current probability of presence, the project partners used the U.S. Geological Survey (USGS) habitat potential model (Nussear et al. 2009). The USGS model reflects historic or pre-human-altered habitat potential, so from this the research team subtracted *impervious surfaces*, as defined by the National Landcover Dataset (Fry et al. 2011). Impervious surfaces have zero probability of desert tortoise presence. The impervious surfaces layer includes: (1) developed open space (imperviousness < 20 percent), (2) low-intensity developed space (imperviousness from 20 - 49 percent), (3) medium intensity developed space (imperviousness from 50 -79 percent), and (4) high-intensity developed space (imperviousness > 79 percent). If there are areas of potential habitat smaller than 1km² that are surrounded by areas of zero habitat potential, then these areas are also set to zero probability of presence since it is unlikely that these isolated “islands” of habitat can be accessed by tortoises (Figure 27).

Figure 27: Probability of Presence Map Layer Used in the Third Iteration SDSS



The probability of presence surface is calculated by removing impervious surfaces from the USGS Habitat Potential surface. Darker green represents higher habitat potential or probability of presence values.

Source: Desert Tortoise SDSS, Third Iteration; USGS Habitat Potential Model (Nussear et al. 2009).

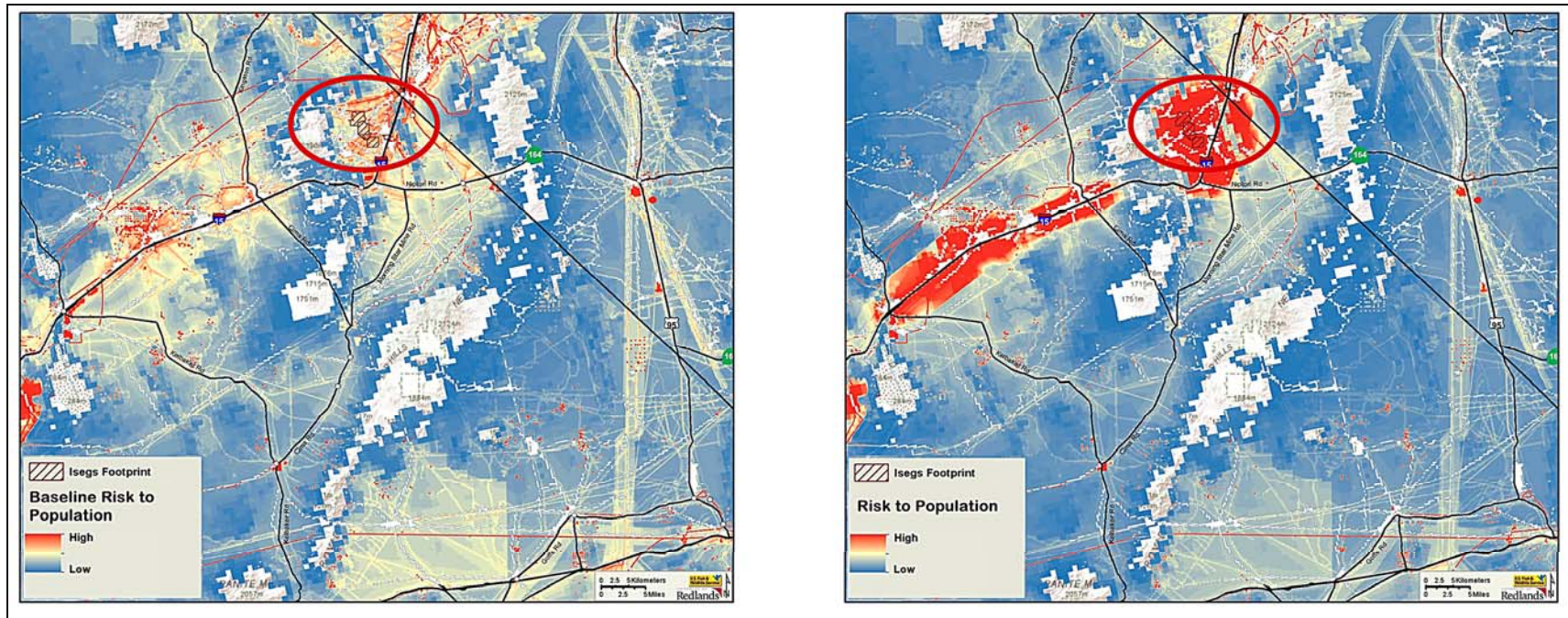
The value of the probability of presence surface at a point indicates how suitable that area is for the desert tortoise. For those areas that have a high (close to 1) value but currently no desert tortoise population, the quality of the habitat is such that in the future a population may return and thrive there, a critical consideration in terms of species recovery.

The project partners integrated this probability of presence surface into the main spatial calculations by multiplying all derived contribution to population change values at every point by the corresponding value of the probability of presence surface at that point, to arrive at an improved method for calculating risk to the population at each point across the range of the tortoise.

By incorporating probability of presence, risk to the population is no longer assigned to areas on the landscape where tortoises do not live now and will not live in the future. For example,

without considering the probability of desert tortoise presence, the Desert Tortoise SDSS would report that there are a large number of threats contributing to risk to the tortoise population in Las Vegas, and it would therefore be an area to consider for recovery. However, due to the large number of human impacts and impervious surfaces in Las Vegas, there are no tortoises there anymore. Using the probability of presence calibrates the models such that Las Vegas has a zero probability of tortoise presence and therefore is not a high risk area for desert tortoises and not an area in which to focus recovery efforts (Figure 28).

Figure 28: Change in Risk to the Population Incorporating Probability of Presence



Change in risk to the population that incorporates probability of presence, before (left) and after (right) placement of a proposed solar energy project prior to assigning recovery actions. Areas of high risk are shown in darker red; areas of lower risk in darker blue.

Source: Desert Tortoise SDSS, Third Iteration; USGS Habitat Potential Model (Nussear et al. 2009).

3.3.2 Summary of Calculation in the Third Iteration SDSS

The computational approach for the third iteration of the Desert Tortoise SDSS was similar to that for the second iteration, with the changes to system models and calculations noted above:

- (1) Acquire spatial maps of the intensity of identified threats (existing and proposed).
- (2) Normalize each individual threat layer across the range, to create a normalized threat layer.
- (3) If the footprint of the effect of the threat is different than the threat itself, apply the appropriate buffers to produce the ecological effect area layer, and spatially normalize the resulting layer.
- (4) Multiply each normalized threat or threat ecological effects layer by the threat-stress weight, and sum the weighted layers across the range to estimate the resulting stress layer.
- (5) Multiply each stress layer by its direct stress weight, then sum all the contributions to population change at every point to estimate the spatially-explicit contribution to an increase in risk to the population.
- (6) Multiply all derived contribution to population change values at every point by the corresponding value of the probability of presence surface at that point.
- (7) Obtain footprints for where recovery actions would be implemented, and buffer to their effective extent if applicable.
- (8) Multiply the contribution of every *affected threat* in the area where that recovery action is implemented by the effectiveness weight for that recovery action acting on that threat; and sum across all reductions in affected threats, at every point, to estimate the overall reduction in contribution to change in risk to the population due to that recovery action.

As before, the change in risk to the population is calculated by estimating the risk before a proposed solar energy development project is added to the virtual landscape, and the net risk (direct and indirect plus recovery actions) after it has been added.

The three sections in this chapter have provided the definitions and theory that underlie all the other tasks undertaken during the California Energy Commission project, which are described in the next chapter. Table 3 compares key features of the system at each iteration to summarize changes to system models and calculations.

Table 3: Comparative Summary of the Three System Iterations

Conceptual, Computational and Validation Capacity	First Iteration	Second Iteration	Third Iteration (Energy Commission)
Conceptual Model: Risk characterization	Adult Mortality	Population Change	Risk to Population
Conceptual Model: Probability of Presence	No	No	Yes
Conceptual Model: Management	Hard-wired	Conceptual Model Manager tool	Conceptual Model Manager tool
Conceptual Model: Threat Chain	Threats > Threats > Mortality Mechanism > Adult Mortality	Threats > Threats > Stresses > Population Effects > Population Change	Threats > Threats > Stresses > Population Effects > Population Change
Conceptual Model: Recovery Actions	Suppress Threats	Suppress Threat-Stress mechanisms	Suppress Threat-Stress mechanisms
Conceptual Model Development & Review	DTRO	DTRO, DT Biologists & Managers	DTRO, DT Biologists & Managers, Science Advisory Committee , RITs
Computation: Decrease in Risk due to Recovery Actions	Yes, range wide	Yes, area wide	Yes, site specific
Computation: Increase in Risk with Increase in Threat	No	Somewhat	Yes
Computation: SDSS Engine	Model Builder	Python	Web services
Analysis: Spatial Sensitivity Analysis & Uncertainty	No	No	Yes

CHAPTER 4:

Extension of the SDSS for Solar Energy Projects

This chapter describes the core work performed under the California Energy Commission grant in several areas:

- Data management (**Section 4.1**)
- Improvements in the conceptual model, and initial efforts to improve demographic modeling (**Section 4.2**)
- Validation of the modeling and data (**Section 4.3**)
- A case study using a beta version of the system for a preliminary assessment of the desert tortoise mitigation proposed for a solar energy development project (**Section 4.4**)
- Improvements to the system architecture and engine processing and creation of tools for exploring data and models (**Section 4.5**)
- A web-based portal for authenticated users to access the core tools of the system for solar energy project impact and recovery action mitigation calculations (**Section 4.6**)
- Initial efforts to estimate uncertainty in model outputs (**Section 4.7**)

4.1 Data Management

There are 44 threats in the Desert Tortoise SDSS conceptual model (see Appendix A for a complete list). For each threat to the desert tortoise, the system uses a range-wide map layer whose value at each point represents the intensity of the threat at that point (the *threat intensity layer* described in Section 2.2.3). As this is a *spatial* decision support system, these GIS data layers and their attributes and spatial accuracy are critical to the system's structure and greatly influence the results. These spatial datasets inform the system calculations, and ultimately the decision maker, about where threats exist and to what degree that threat location contributes to tortoise population decline. When the spatial extent of a threat is missing, or its intensity is misunderstood or misinterpreted, the calculations and results can be affected across the range. While it may not be possible to have complete and accurate data for all of the threats included in the system, the project partners are committed to using the best available data for system calculations. Therefore, efforts to collect, assess, document, manage, and curate the spatial data are central to each iteration of the system.

4.1.1 Data Acquisition and Creation

Data development for the third system iteration started with acquisition of the most current, existing datasets from public sources to represent the spatial distribution of each of the 44 threats in the model. The project partners made every attempt to search, request, and acquire data from various sources and cross reference them to ensure the system is using the most current and accurate data available. The large range of the desert tortoise, which crosses four states and multiple jurisdictional boundaries, complicates this effort. Where possible, the project partners acquired source datasets that encompass the entire range of the tortoise, to preserve

data integrity and avoid inconsistencies across boundaries. However, many spatial datasets are not available range wide or even state wide and must therefore be aggregated or “stitched” together so that their combined extent crosses the entire range. In these cases, data was integrated across sources and standardized attributes (e.g., BLM’s grazing data). In addition, when conflicts were found between datasets and/or datasets were out of date, the project partners contacted experts for each threat to determine which dataset is most appropriate for use in decision making.

Along with data on threats, the project partners attempted to acquire datasets representing existing, implemented recovery actions such as tortoise fencing and educational kiosks. These datasets help calibrate the system’s results to avoid duplication, so that a recovery action is not suggested in an area where that action has already been implemented. Spatial datasets for many of the recovery actions represented in the conceptual model were largely unavailable from the implementing agencies. The project partners will continue to acquire and implement these data on an ongoing basis (see Appendix E).

It is essential that system users (project proponents, regulators, scientists and resource managers and the public) understand who created source data, and how, why, and when it was collected. The project partners endeavor to acquire spatial metadata along with the datasets themselves, and to use this metadata to assess spatial datasets for model integration. If no metadata exists and the providing individual or agency are not available to verify key information about the data, the dataset is not used.

Data sources include: all four (AZ, CA, NV, and UT) state BLM data sites, state GIS databases, USGS, EPA, the Census Bureau, National Park Service, Great Basin Center for Geothermal Energy, Esri, California Department of Forestry and Fire Protection, California Resources Agency, National Transportation Atlas Database, Caltrans, University of California – Riverside, California Integrated Waste Management Board, Argonne National Laboratory, Desert Managers Group, Edwards Air Force Base, and various off-highway vehicle desert racing groups. Other data sources outside of California include the Arizona Department of Environmental Quality, Utah Department of Environmental Quality, Nevada Division of Environmental Protection, Colorado State University Natural Resource Ecology Laboratory, Red Cliffs Desert Reserve, and the University of Nevada at Reno (Appendix E).

4.1.2 Data Curation and Review

All datasets, both those used and integrated within the Desert Tortoise SDSS and those not used, have been cataloged in a data inventory with the threat or recovery action type, description, data source and URL, year, status, map and model notes, and any selection or filter criteria identified (Figures 29 and 30). The data inventory indicates why some datasets that have been reviewed and catalogued are not included in the SDSS (e.g., insufficient metadata, incompatible, etc). The data inventory system is an internal instance of Microsoft® SharePoint online collaboration software that catalogs the data resources, with hyperlinks to the metadata, map images, and data layer packages posted to the Web server. Current spatial data holdings include 288 threat layers, 147 of which are used in the system. (The reasons why some threat layers are not used is explained in Section 4.1.2.1.) The inventory also includes 180 “base data

layers” which may be used by the system’s various components for informational purposes but are not used explicitly for modeling purposes (e.g., landscape features and landmarks, jurisdictional boundaries, habitat resources).

Figure 29: Data Inventory of Spatial Datasets in the Desert Tortoise SDSS

Edit	In DSS	Appropriate for RIT Area(s)	Threat Type†	Threat	Dataset Name	Dataset Title	Selection Criteria	Data Source	Year	Data Notes	Feature Type	Buffer (m)
	Yes	CA Mojave, NE Mojave, Upper Virgin River	Agriculture	Agriculture 2006	NLCD_2006_Swclip	National Land Cover Data 2006	Land_cover = Pasture/Hay, Land_cover = Cultivated Crops	U.S. Geological Survey	2006		Raster	0
	Yes	NE Mojave	Agriculture	Agriculture	NV_Cropland_NyeCo	NV_Cropland_NyeCo			2012		Polygon	
	Yes	CA Mojave	Air Pollution	Nitrogen Deposition	CA_NitrogenDep	Total Nitrogen deposition for California during 2002		University of California - Riverside	2007		Raster	0
	Yes	CA Mojave, NE Mojave, Upper Virgin River	Altered hydrology	Altered hydrology	ALTEREDHYDRO	Altered Hydrology in the Mojave Desert		The Redlands Institute, University of Redlands	2011	modeled data	Raster	
	Yes	CA Mojave, NE Mojave, Upper Virgin River	Aqueducts	Aqueducts	SW_AqueductCanals	Aqueducts & Canals in the Southwest US	FTYPE2 = Aqueduct	ESRI® Data & Maps 2010	2011	FTYPE2 and NAME2 columns were added to ESRI data (dtl_riv). Aqueducts were reattributed and named according to http://www.maps.com/ref_map.aspx?pid=11649 . Colorado River Aqueduct line replaced with file sent by Stewart A. Cook (Mark Massar) BLM Palm Springs 5-23-12	Line	0
	Yes	CA Mojave, NE Mojave, Upper Virgin River	Captive Release or Escape	Unauthorized Release or Escape of Captive Tortoises to the Wild	CAPTIVERELEASE	Unauthorized Release or Escape of Captive Tortoises to the Wild		The Redlands Institute, University of Redlands	2011	modeled data	Raster	
	Yes	CA Mojave, NE Mojave, Upper Virgin River	Coyotes & Feral Dogs	Coyotes & Feral Dogs	COYOTEFERALDOGS	Predators (non-raven) in the Mojave Desert		The Redlands Institute, University of Redlands	2011	modeled data	Raster	
	Yes	CA Mojave, NE Mojave, Upper Virgin River	Disease	Disease	DISEASE	Disease in the Mojave Desert		The Redlands Institute, University of Redlands	2011	modeled data	Raster	

All spatial datasets are cataloged in a Microsoft® SharePoint instance.

Source: Desert Tortoise SDSS, Third Iteration

Figure 30: Example of Details for Spatial Datasets in the Inventory

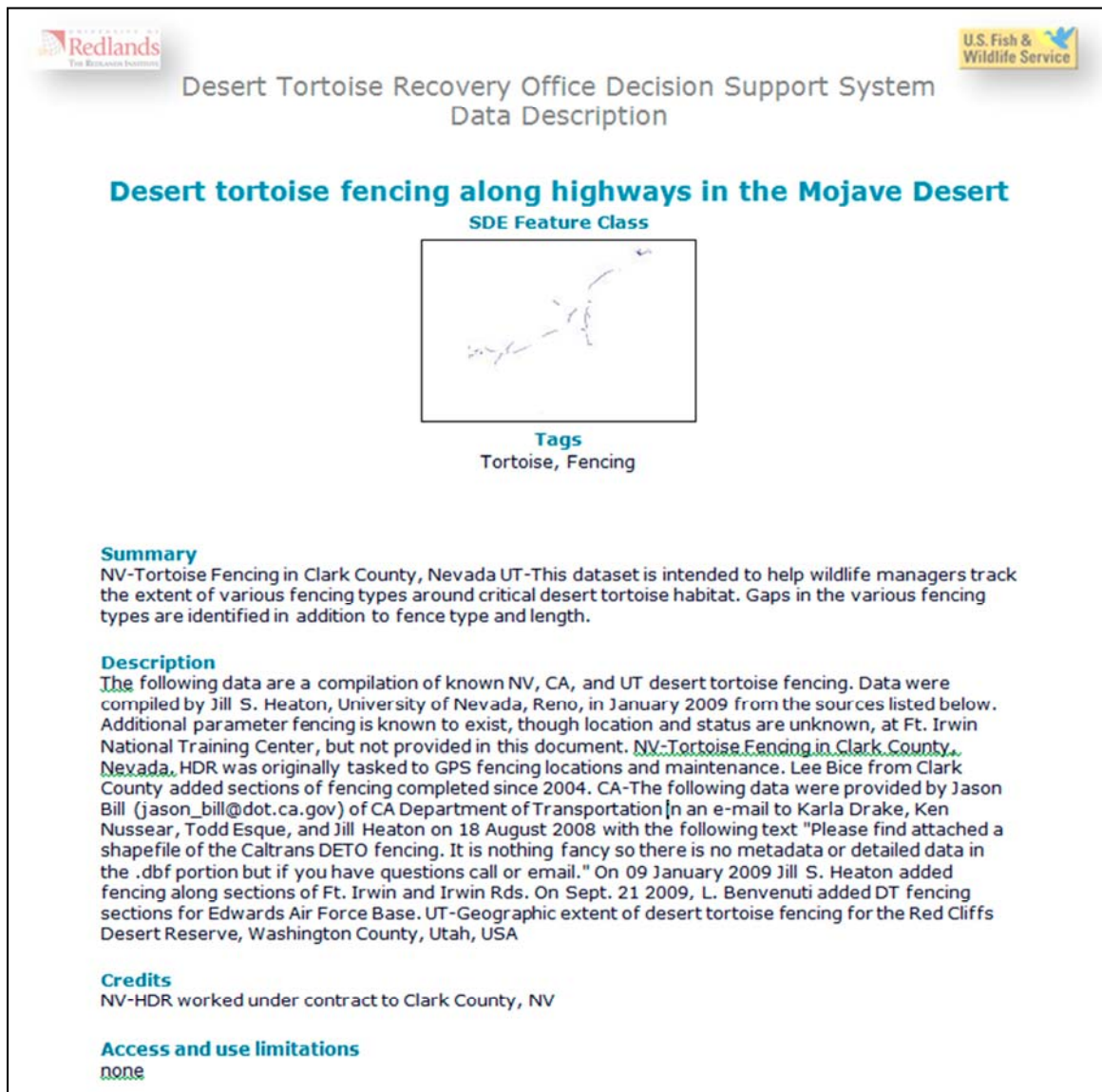
The screenshot shows a SharePoint web application interface. The top navigation bar includes site actions like 'New Item', 'New Folder', 'View Item', 'Edit Item', 'Delete Item', 'Attach File', 'Alert Me', 'Workflows', 'Approve/Reject', 'I Like It', and 'Tags & Notes'. The main content area displays a table of dataset details.

Dataset Name	CA_NitrogenDep
Updated per Webinar	Yes
In Map Service	Yes
In DSS	Yes
Appropriate for RIT Area(s)	CA Mojave
Threat Type	Air Pollution
Threat	Nitrogen Deposition
Dataset Title	Total Nitrogen deposition for California during 2002
Description	Provides a geography of annual nitrogen deposition throughout most of the state of California including locations where there are no measurement data. Supports study of effect of anthropogenic nitrogen on the structure and function of terrestrial ecosystems.
Selection Criteria	University of California - Riverside
Data Source	http://ccb.ucr.edu/biocommmaps.html
Source URL	http://ccb.ucr.edu/biocommmaps.html
Year	2007
Feature Type	Raster
Status	Complete
Data Notes	
Map/Model Notes	use for CA Air Pollution Solar 1 calculations
Buffer (m)	0
Intensity Value (0-1), Field, or Process	Rescale (std)
Overall Confidence	Medium
Spatial Confidence (+/- meters)	
Metadata Summary	http://www.spatial.redlands.edu/DTRO/resources/Metadata/DTRO Summary/DTRO NITROGENDEP Metadata.pdf
Metadata FGDC	http://www.spatial.redlands.edu/DTRO/resources/Metadata/FGDC HTML/NITROGENDEP.html
Map Image Link	http://www.spatial.redlands.edu/DTRO/resources/MapImages/NitrogenDepositionCA.jpg
Data Download Link	http://www.spatial.redlands.edu/DTRO/resources/Shapefiles/N_deposition_2002.zip
Layer Pkg	http://www.spatial.redlands.edu/DTRO/resources/LayerPkg/Threat - Air Pollution.lpk
Map check June 2012	Yes
Edit	

Source: Desert Tortoise SDSS, Third Iteration

The spatial datasets themselves are stored in a Microsoft SQL Server database using Esri's ArcGIS Server Enterprise Advanced® and managed using Esri's ArcGIS Desktop® suite of products. For each dataset that is used by the Desert Tortoise SDSS, a *summary data description*, detailed metadata, and a map image are provided for system users. The summary data description (Figure 31) is a simplified, high-level version of the metadata intended for decision makers, in contrast to the detailed metadata required by a GIS analyst. These summary data descriptions include information such as from where the dataset was acquired, how recently it was created, the individual or agency source(s) of the data, and for what purpose it is used in the system.

Figure 31: Example of Summary Data Description for Spatial Datasets



The Data Description is a reader-friendly summary of the dataset's metadata.

Source: Desert Tortoise SDSS, Third Iteration

For GIS analysts and system users to assess these data, and ultimately for publishing the data for scientific reuse, detailed Federal Geographic Data Committee (FGDC) compliant metadata has been created and/or updated for each dataset (Figure 32). The project partners also manually produced maps and map images for each threat in the conceptual model to provide users with a quick and simple view of the spatial data layers employed by the system.

Figure 32: Metadata for Spatial Datasets in the System



Detailed FGDC-compliant metadata is maintained for each dataset. This FGDC metadata includes scale and resolution information, when available.

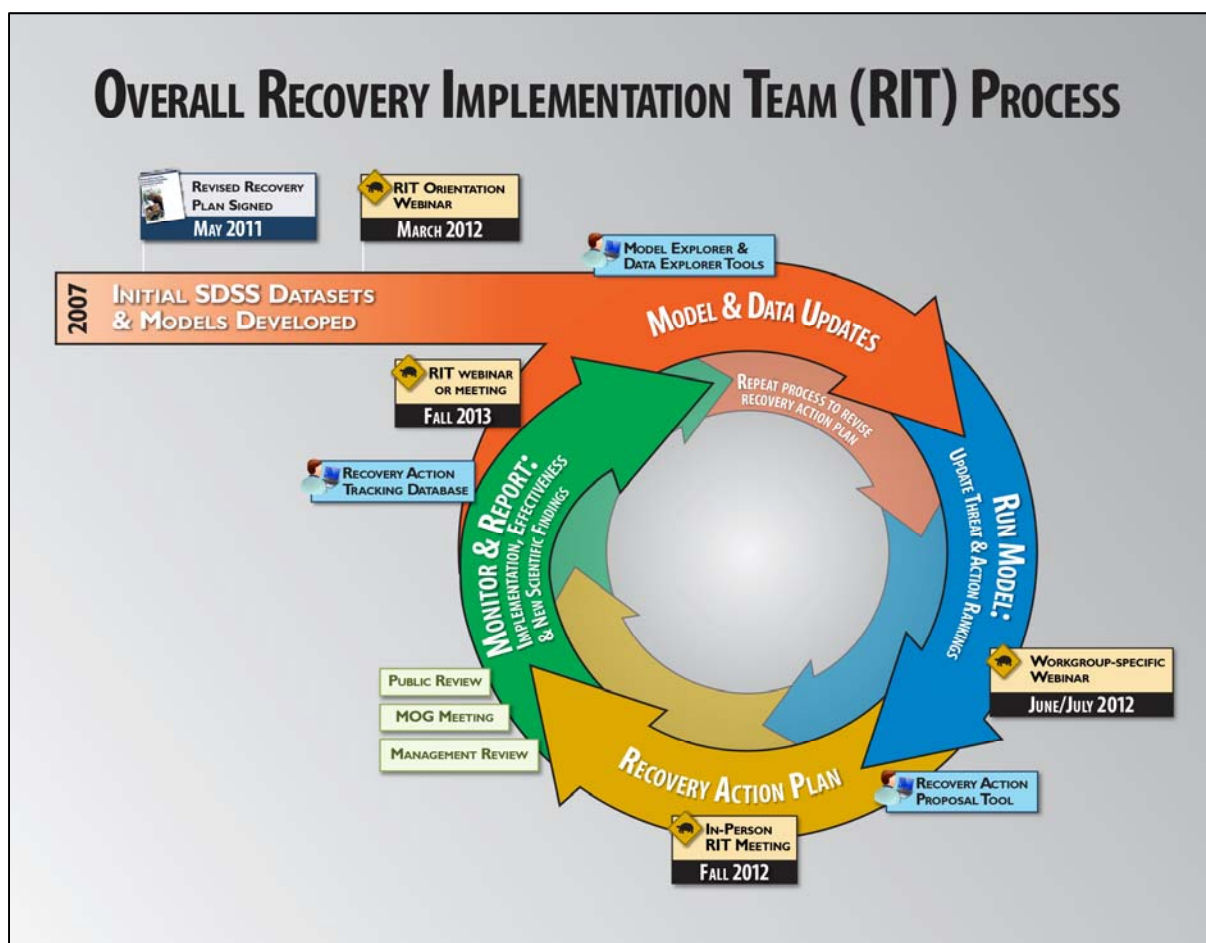
Source: Desert Tortoise SDSS, Third Iteration

These system data and metadata products are publicly available for review and download from the Desert Tortoise Recovery *Data Explorer* website

(<http://www.spatial.redlands.edu/dtro/DataExplorer>). See Section 4.3.1 for more information on the Data Explorer website and tools.

Data curation and management is an iterative process that involves the ongoing acquisition and assessment of new or updated datasets. These datasets need to be compared to existing project data and differences evaluated. Once the new data is deemed fit for the system, the inventory is updated, the dataset is added to the SDE, and is published to the Web via Web services that feed the Data Explorer with all associated documentation at each step. Some datasets are rarely updated unless there is a new detailed survey. Others, such as land ownership data, change almost daily. Some critical threats datasets may be updated as needed but the entire base data and threat data update process for this project will follow a two year cycle (Figure 33), in step with the FWS Recovery Implementation Team process. (For more about this process, see Section 4.3.) Implemented recovery actions will be updated, mapped, and documented as needed but will not be incorporated into the models until the two year scheduled update.

Figure 33: Two Year Iterative Cycle for Recovery Action Planning and Data Updates



The two year data curation cycle fits within a larger bi-annual desert tortoise recovery action planning and implementation cycle that collaboratively uses, validates and generates additional data.

Source: FWS

4.1.2.1 Discussion of Data Curation

In the course of this research, the project partners have: (1) codified, streamlined, and made collaborative the data curation process, (2) expanded the network of sources of datasets used by the system, and (3) adopted standards in metadata and Web service publishing. As a result, the Desert Tortoise SDSS now includes the most comprehensive range-wide threats datasets for desert tortoise. Stakeholders can access the data through the Data Explorer, and download datasets for their use. In addition, much of the public data is published through Esri's ArcGIS.com data catalogue where other users can search and access these data.

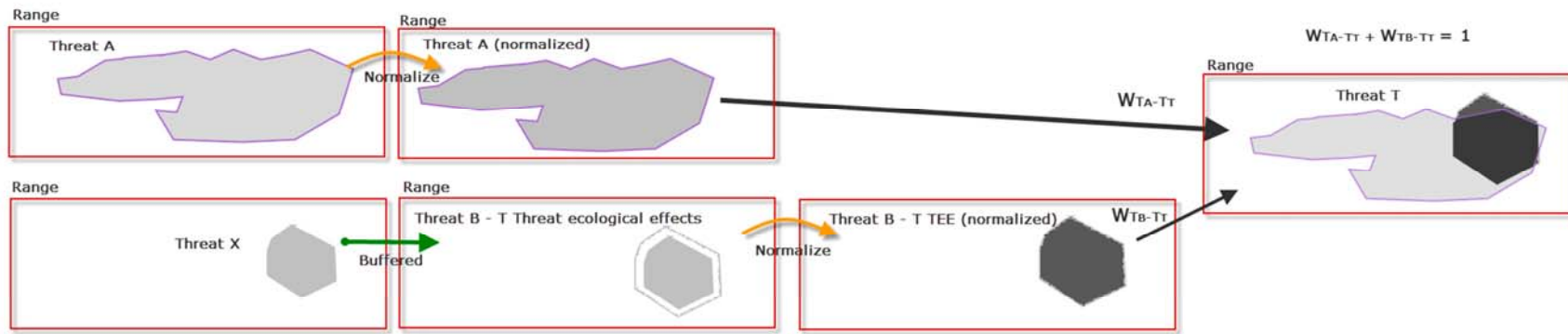
As for so many data-intensive efforts, issues around data availability and reuse are a central challenge:

- Nonexistent data: for some known threats the spatial data simply do not exist (e.g., spatial distribution of disease prevalence in the tortoise population).
- Insufficient data: either available data does not cover the entire study area, or is too sparse, or is unavailable (e.g., tortoise demographic plot data in California).
- Incompatible data: data collected by different agencies for different purposes may not always be compatible (e.g., mining locations).
- Data conversion: many times data is collected by an agency and is provided as tables or text that need to be spatially referenced (e.g., footprints of existing solar plants needed to be digitized from imagery based on general location information).

4.1.3 Derived Threat Layers

For a threat (e.g., "Disease") where no suitable existing spatial dataset is available, and which, according to the conceptual model, is fully accounted for by the other threats that contribute to it, then as a last resort the project partners calculate a *derived threat layer* for that threat (Figure 34). The derived threat layer is produced using a similar process to that for calculating a stress layer from its contributing threats.

Figure 34: Example of Spatial Calculation for Derived Threat Layers



Deriving Threat T from its two contributing threats A and X. Threat X has an ecological effects area when contributing to Threat T. Threat T is derived from its contributing Threats as the weighted overlay of its normalized contributing Threats (or their threat ecological effects area, if applicable), and the weights are those from the conceptual model.

Source: Desert Tortoise SDSS, Third Iteration

In the third iteration of the Desert Tortoise SDSS, there are ten derived data layers:

- Distribution of air pollution (in Nevada, Arizona and Utah)
- Anthropogenic-caused areas of altered hydrology
- Locations with high risk of release or escape of captive tortoises
- Coyote and feral dog prevalence
- Disease prevalence
- Fire potential (in Nevada, Arizona and Utah)
- Occurrence of fugitive dust
- Garbage and dumping
- Anthropogenic-caused areas of surface disturbance
- Prevalence of toxicants

Pragmatically these derived layers represent a temporary strategy, and are part of a process of identifying data gaps. If in the future researchers can provide suitable range-wide spatial datasets, these new layers would replace any derived layers. (For definitions of threats included in the conceptual model, see Appendix A.)

4.1.4 Spatial Constant Surfaces

Four threats (“Storms and Flooding,” “Shift in Habitat Composition/Location,” “Temperature Extremes,” and “Drought”) are natural processes that can be exacerbated by human activities that influence climate change (Christensen et al. 2007). However, the stochastic (random) nature of these threats is beyond the scope of this iteration of the system. Therefore, the spatial extent of these threats is represented by a spatial layer whose intensity is constant across the range (a *spatial constant layer*), in order to capture a baseline level of interaction with other threats or stresses. Again, these spatial constant layers represent a temporary strategy and are part of a process of identifying data gaps. If range-wide spatial datasets become available in the future, these layers would replace any spatial constant layers.

4.1.5 Threat Layer Model Integration

Once spatial datasets have been acquired, assessed, and identified as appropriate for use within the system, data processing must be done to standardize and integrate each dataset. Although steps have been taken (and will continue) to streamline and automate much of this process, some manual (or semi-manual) steps are still required for every threat. The project partners plan to fully automate the steps listed below through a tight integration of the data inventory and conceptual model in future system iterations.

4.1.5.1 Threat Intensity Assignment

As described in Section 2.2.3, for each threat in the model there is a range-wide map layer whose value at each point represents the intensity of the threat at that point. Recall that this

threat intensity map is either: (1) an extent (a footprint) with binary (1, 0) values, or (2) a map layer with continuous and differing values at different points on the map. In any given area, the different threats are more or less present according to their spatial distributions. However, each map could be on a completely different scale, complicating direct comparisons between maps as to how the threats affect tortoises. Therefore, the attribute values must be interpreted and assigned an intensity value on a scale of 0-1 by implementing the *spatial normalization* process described in Section 2.2.3.

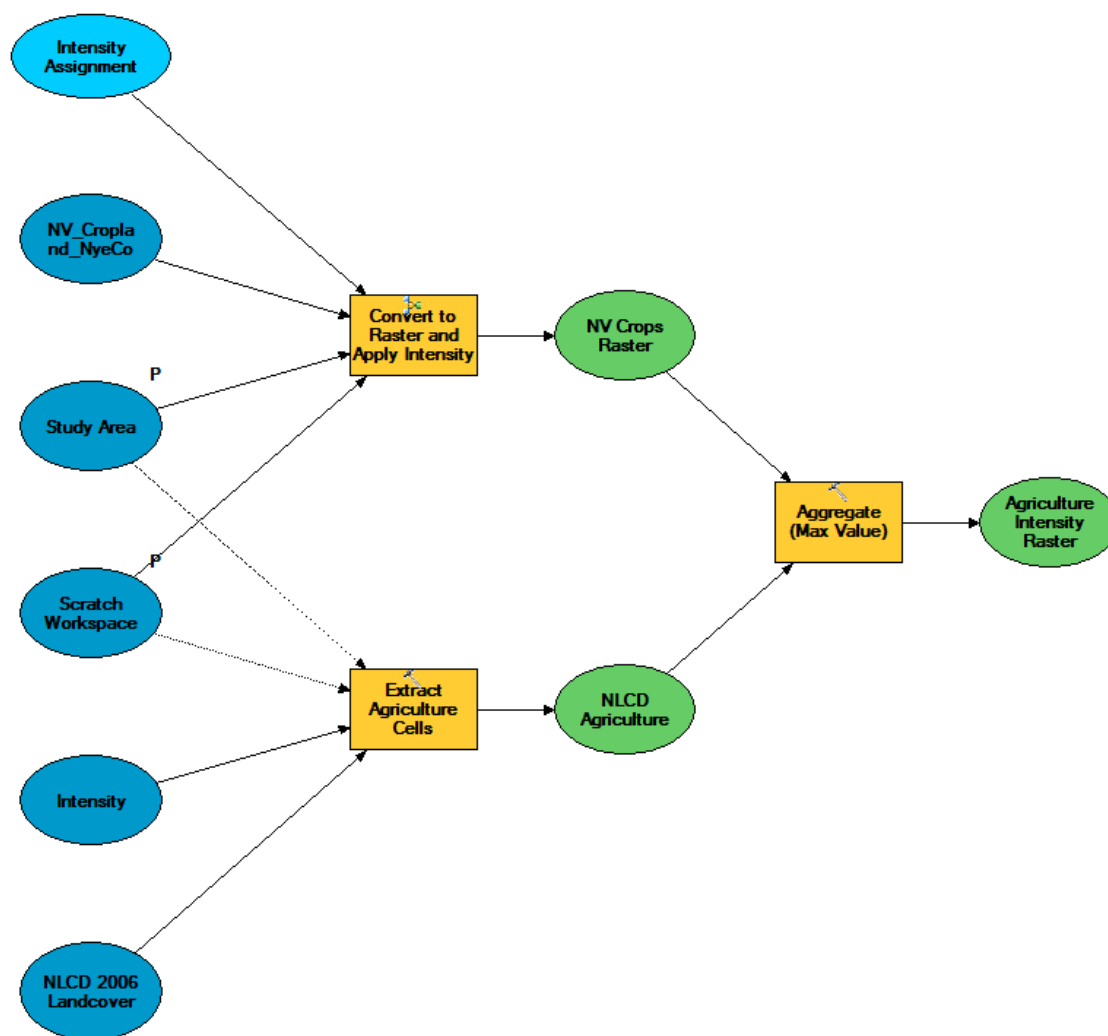
4.1.5.2 Raster Conversion

The system's spatial processing engines have been designed to use *raster data* and processing methods. GIS raster data is structured as an array of square cells (pixels) in geographic coordinate space where each pixel is coded with a single value (with the potential for more values based on format and data type constraints). When raster datasets share the same origin coordinates and cell size, overlay operations become computationally fast and efficient. However, the majority of source datasets for the Desert Tortoise SDSS are in *vector* format (point, line, and polygon).

Spatial precision may be lost with conversion from vector to raster when points or lines are aggregated to one value per raster cell. This is because the conversion entails summarizing and aggregating individual feature values over the cell resulting in a new, possibly less precise value. For this system, the computational efficiency gained by using raster data was judged worth the trade-off. The system's spatial engine currently uses cells of 100m across (10,000 m² or ~2.5 acres) which is a higher resolution than exists in most of the input vector datasets. The value aggregation of source vector data to 100m raster cells is handled differently for each vector input dataset, depending on the parameters of the dataset; generally it can be defined as either the maximum, minimum, or mean value of the features within the 100m cell.

The threat intensity assignment, aggregation, and combination operations in the system are all captured, modeled, and processed using Esri's ArcGIS® ModelBuilder as individual geoprocessing models (Figure 35). ModelBuilder is a tool to visually author, manage, and execute complex geoprocessing workflows (Esri 2011). By using ModelBuilder to automate these steps, the processes are fully captured, documented, and reproducible.

Figure 35: Esri ModelBuilder for System Geoprocessing



Threat Intensity Layers are created using Esri's ArcGIS® ModelBuilder. This Threat Intensity model for "Agriculture" (1) extracts cells classified as "Agriculture" from the National Landcover Dataset; (2) converts a polygon vector file of croplands to a raster dataset; (3) assigns intensity values of one (0-1 scale) of the two individual layers; and finally (4) overlays those rasters into a single intensity grid by taking the maximum value at any one raster cell location.

Source: Desert Tortoise SDSS, Third Iteration

4.2 Extending the Conceptual Model

The project partners identified and implemented three important updates to the conceptual model that were necessary to reliably calculate the impact of solar energy development projects on the risk to the desert tortoise population:

- (1) Separated the threat of "Solar Energy Development" from the original, more general threat of "Energy Development."
- (2) Reviewed the entire conceptual model against the latest scientific literature.

- (3) Researched whether it was possible to improve system modeling of the contribution of population effects to population change, by replacing the existing linear weighted model with a formal demographic model.

4.2.1 Deep Review of the Conceptual Model

The revised Recovery Plan for the Mojave desert tortoise, published in 2011, contained the most up to date threats assessment and recovery recommendations (USFWS 2011). In response to this, on April 20-21, 2011 the project partners held an intensive conceptual model review workshop in Reno, NV with all members of the FWS DTRO team. Taking Appendix A in the revised Recovery Plan as a starting point, workshop participants re-evaluated individual threats and stresses, re-assessed the contribution of stresses to population effects, and revisited all citations in the conceptual model. The results of that review are fully documented in Appendix A; the highlights are described below.

The project partners separated the threat of “Energy Development” into (1) “Solar Energy Development,” (2) “Wind Energy Development,” (3) “Oil and Gas Development,” and (4) “Geothermal Energy Development,” as these were found to have slightly different effects on desert tortoise populations. The FWS DTRO team confirmed that most links associated with energy development were valid for solar energy development and re-examined the related model weights based on this expert advice. The review resulted in the following conceptual model elements directly related to solar energy development:

Direct effects on population stresses

Habitat Loss: defined in the DTRO SDSS conceptual model as “Land area subject to the complete or absolute removal of elements necessary for desert tortoise occupation (i.e., grading or paving of the landscape, removing all feeding, sheltering or breeding resources) or that falls below other identified thresholds of habitat quality required to support desert tortoises.” Solar energy development poses a significant threat to desert tortoises through habitat loss and fragmentation (Luke et al. 1991; Lovich and Bainbridge 1999; LaRue and Dougherty 1999; Lovich and Ennen 2011; Averill-Murray et al. 2013). The recent public emphasis on advancing alternative energy sources has emerged as a source of large-scale, permanent habitat loss for desert tortoise (USFWS 2011). Consultations with regulatory biologists confirmed that solar energy development projects result in total habitat loss because the areas are denuded of all vegetation, graded and fenced (the equivalent of being paved) and all tortoises are removed from the area.

Crushing: defined in the conceptual model as “Mortality due to excessive force or weight being exerted on animal either above or below ground.” Tortoises may be crushed during exploration, construction and ongoing operations, and maintenance activities associated with solar energy development (USFWS 1994; Boarman 2002; Lovich and Ennen 2011).

Population Fragmentation: as defined in the conceptual model, “Results from barriers to movement from urbanization, fences, roads and railroads, aqueducts, and energy development, and can limit the movement of animals, their ability to behaviorally improve their chance of survival. This

lack of movement is accompanied by a proportional reduction in flow of genetic material and an increase in mortality reducing genetic diversity and the ability to adapt to changing conditions."

Population fragmentation can result because of discontinuities in once continuous habitat, frequently caused by clearing of native vegetation for activities such as solar energy development (Luke et al. 1991; Lovich and Bainbridge 1999; LaRue and Dougherty 1999; Lovich and Ennen 2011; Averill-Murray et al. 2013). Impacts of population fragmentation on loss of genetic diversity, inbreeding depression, and increased extinction risk depend on the level of gene flow that is lost among the fragments (Frankham et al. 2004).

Small Population and Stochastic Effects: as defined in the conceptual model, "*Small populations have a higher likelihood of extirpation as a result of any mortality (or recruitment) effect.*" Human-related factors often reduce populations to sizes where species are susceptible to stochastic, or accidental, effects. Environmental and demographic stochasticity and the impact of catastrophes interact with genetic diversity in their adverse effects on populations. Smaller populations lose genetic variation and consequently are less able to adapt to changing environments and more susceptible to catastrophic effects of stochasticity creating a feedback loop of increased risk of extinction (Frankham et al. 2004).

Indirect effects through resulting threats: Six of the original indirect threats pathways were confirmed, and a new threat-to-threat link (from "Solar Energy Development" to "Ravens") identified:

Utility Lines and Corridors: as defined in the conceptual model, "*Utility corridors and lines including transmission and power lines and poles, and oil and gas pipelines.*" Solar energy development can result in the proliferation of utility lines and corridors to transport power to population centers.

Paved Roads: defined in the model as "*Linear corridors that have been finished with asphalt or concrete, typically impervious, to support vehicular or other travel.*" Energy development can result in the proliferation of paved roads to transport people and goods.

Surface Disturbance: Conversion of desert tortoise habitat to solar energy development can result in surface disturbance, defined as "*Disruption or removal of natural surface soil and vegetation.*"

Unpaved Roads: defined as "*Dirt or gravel secondary or tertiary roads, often labeled as accessible to 4-wheel drive vehicles only (includes BLM's open OHV routes).*" Solar energy development can result in the proliferation of unpaved roads to transport people and goods.

Fire potential: defined in the conceptual model as the "*Potential for human or naturally caused fire in desert tortoise habitats.*" Infrastructure associated with solar energy development can pose a fire risk (Tsoutsos et al. 2005).

Toxicants: Solar energy development can introduce toxins into environment (Boarman 2002; Tsoutsos et al. 2005; Lovich and Ennen 2011), including a variety of hazardous materials used in construction and operations as well as pesticides and herbicides for site

maintenance. Toxicants are defined as *“Airborne particulate matter containing toxicants released from anthropogenic sites such as mines, roads, construction, and other disturbances.”*

Ravens: Utility-scale solar developments create increased infrastructure for ravens, defined in the conceptual model as *“Corvus corax; considered a human-subsidized predator of mostly hatchling and juvenile desert tortoises.”* USFWS regulatory biologists have emphasized the importance of tall structures as perching sites for subsidizing raven population.

All of these impacts, direct and indirect are included in the conceptual model and executed in the computational models of the third iteration of the Desert Tortoise SDSS. (See Figure 25 for an expanded view of how the indirect impacts via corollary threats result in generations of impacts.) These changes were concurrent with others being made to the conceptual model. The project partners also merged, renamed, split apart or removed a number of other threats and stresses in the model to make the model align better with current scientific literature. Where interactions disappeared, weights were renormalized. Where interactions were added, weights were estimated based on the expert weights of similar interactions.

The project team presented the revised relationships in the conceptual model to several groups, and implemented a number of changes based on their feedback:

- Presentations at two workshops with the Desert Tortoise Science Advisory Committee (March 4, 2011 Palm Desert, California; April 20, 2012 Tucson, Arizona).
- A conference call on June 3, 2011 with U.S. Fish and Wildlife Service regulatory biologists who are currently or have recently worked on expert consensus for solar energy development projects to review the details of the inter-threat relationships in the model of the solar energy development impacts to desert tortoise populations.
- A presentation at the Desert Renewable Energy Conservation Plan (DRECP) Stakeholders Meeting on August 17, 2011 in Ontario, California. The project partners received comments and suggestions from stakeholders; initiated potential collaboration with a landscape-scale BLM monitoring proposal; and gained a potentially improved model for utility corridors.
- A follow-up webinar in Fall 2011 with DRECP Resource Mapping Workgroup, at their request, to present datasets that may be useful to their planning process and share requested datasets and model outputs.
- A conference call in Fall 2011 with the Desert Managers Group members involved with the development of solar energy projects and their potential environmental impacts on the desert tortoise. The utility of system modeling in the mitigation planning phase of projects was affirmed at this meeting.
- A formal review of the conceptual model framework and GIS datasets used to represent threats, conducted in Spring 2012 with the FWS Recovery Implementation Teams (RITs). The RITs submitted a total of 168 validation comments via the online Data Explorer and Model Manager tools. These comments led to a small number of valuable

improvements, such as the inclusion of >30 new GIS datasets and 10 new references and two new linkages in the structure of the conceptual model. (See Section 4.3.1)

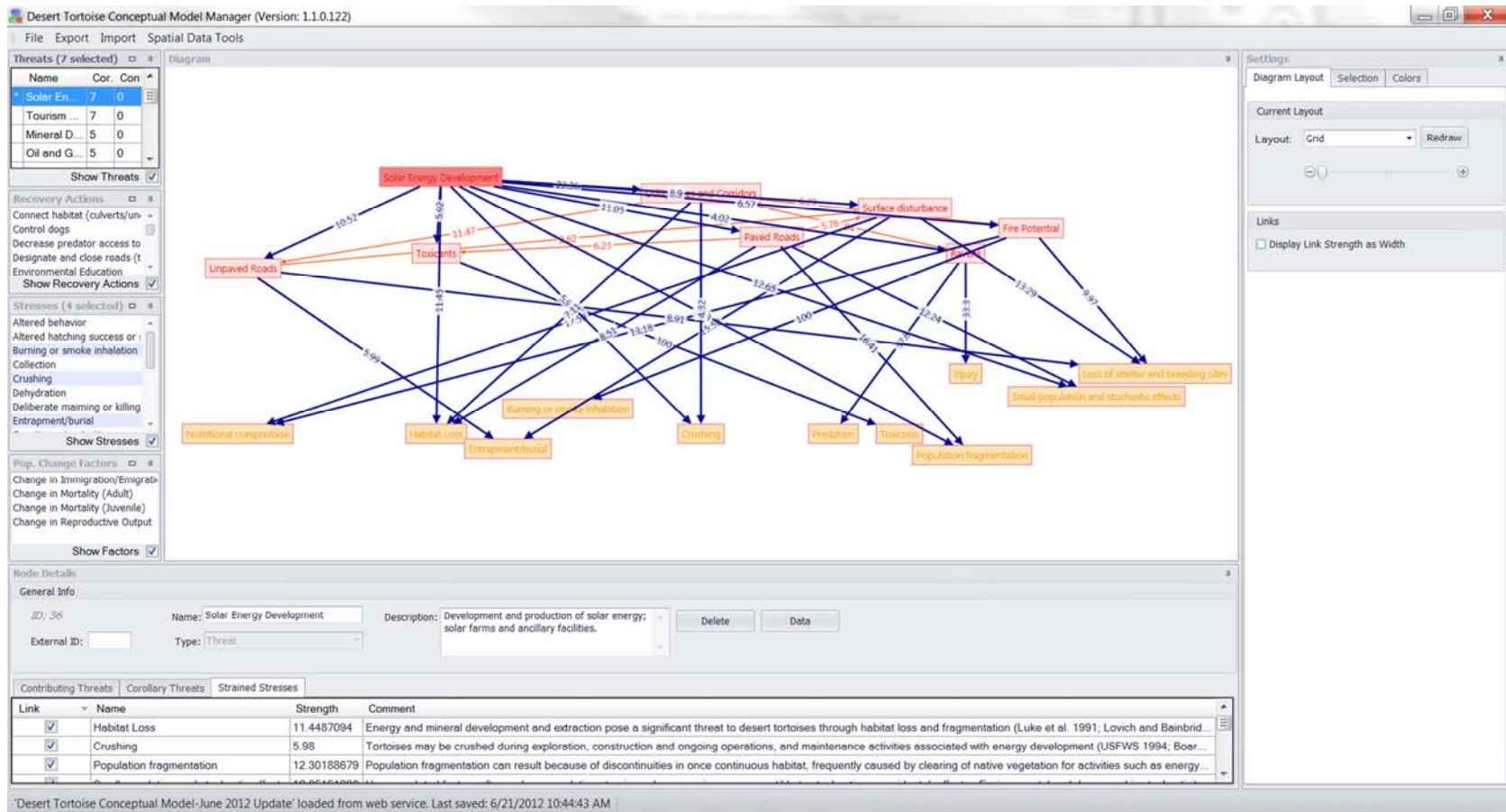
- A presentation to the Renewable Energy Action Team (REAT) on Aug 16, 2012, to discuss how the Desert Tortoise SDSS outputs can inform the DRECP mitigation strategy for the tortoise.

The project partners also presented this research in several professional forums:

- Presented at the Esri Users Conference in San Diego, California during July 11-15, 2011.
- Presented on Recovery Action design and Solar Energy calculations at the Esri User Conference in San Diego, California on July 24, 2012.
- Presented at The Wildlife Society conference in Sacramento, California during Feb 1-4 2012.
- Presented at Biodiversity without Boundaries conference in Portland, Oregon on April 26, 2012
- Poster to National Association of Environmental Practitioners in Portland, Oregon on May 24, 2012

To support this review process and the changes to the conceptual model that resulted from it, the Conceptual Model Manager tool was greatly improved (Figure 36). These changes made the tool more robust, improved visual representation of the complex models, and provided for better annotation of the model including literature citations. With these changes it became possible for DTRO biologist and project team member Dr. Cat Darst to edit, maintain and annotate the conceptual model directly on her desktop, while all changes were recorded on servers at the University of Redlands, and were available for the next system computation.

Figure 36: Conceptual Model Manager with Expanded Conceptual Model



The Conceptual Model Manager can be installed on any Windows desktop, the conceptual models are served from a central server at the University of Redlands via Web services. Changes users make are saved to the server, and are available to other editors and to the Desert Tortoise SDSS computational engine.

Source: Desert Tortoise SDSS, Third Iteration: Conceptual Model Manager

4.2.2 Demographic Modeling

The conceptual model captures how all threats to the Mojave desert tortoise affect overall population change (Darst et al. 2013). The conceptual model explicitly identifies causal relationships among these threats, the mechanisms (stresses) through which the threats affect populations, and which of these linkages are susceptible to specific recovery actions, so that negative impacts on the at-risk species are reduced. Because there are few data available to quantify the *absolute* effects of different threats on desert tortoise populations (Boarman 2002; USFWS 2011), the Desert Tortoise SDSS uses the *relative* contribution of each threat in the model, and then aggregates those contributions to estimate overall risk to the population. Once that is done, the system calculates the changes in risk to the population expected from an increase in threat or implementation of recovery actions.

To improve our methods for quantifying the weights for the relationships between population effects and overall population change, we used elasticity values from an existing population viability analysis for desert tortoises (Doak et al. 1994) that was adjusted to reflect one reproductive and one nonreproductive life stages (Darst et al. 2013). Elasticities are traditionally used to indicate which demographic rates in the model have the greatest effect on population growth rate and persistence (Burgman et al 1993). To modify the original population viability analysis based on eight size classes, we calculated survival rates for juvenile and adult stages as the geometric mean of survival rates of the five smallest and three largest stages, respectively, to reflect the multiplicative aggregate probability of survival through the consecutive classes (Appendix D). Our approach treats tortoises with a midline carapace length up to 180 mm as non-reproductive. We calculated fertility rates as the arithmetic mean of the number of yearlings produced per female in the three largest stages. We conducted new population viability analyses based on demographic rates from the reduced number of stages using the “medium-low” and “medium-high” reproduction levels defined by Doak and others (1994) and averaged elasticities across reproduction levels to generate weights for adult and juvenile demographic rates. The average values were 0.87 and 0.12 for adult and juvenile survival, respectively, and 0.02 for fertility (Darst et al. 2013).

The use of relative values in the Desert Tortoise SDSS model is a barrier to determining the *absolute* rate of population change in response to various threats and recovery actions. Knowing the absolute rate of population change would allow the system to project population trends and calculate how various population stresses may affect overall population viability. Knowing how population viability might be affected by projects or actions would allow the system to calculate the thresholds at which point foreseeable actions may preclude the recovery of the species, or at which point the rate of population change indicates the species is stable. Such calculations would more closely dovetail with the regulatory analyses required for projects that may affect threatened or endangered species.

Calculating the rate of population change (λ) requires estimating absolute demographic rates (i.e., survival and reproduction) resulting from threats, as opposed to relative contributions of each threat to risk to the population. The project partners collaborated with the University of Arizona, Dr. Bob Steidl and Erin Zylstra, to explore available literature that might shed light on

absolute demographic rates in response to threats. If the relative weights in the Desert Tortoise SDSS model could be replaced with models of absolute demographic rates in response to threats, then system data on the spatial extent of each threat could be used to calculate a spatially-explicit corresponding rate of overall population change (λ) across the range of the tortoise. The system could then determine how the implementation of a solar energy development project or implementation of a suite of recovery actions for mitigation would affect the spatially-explicit rate of overall population change and corresponding population viability.

The project partners had hoped to leverage a collaboration with a post-doctoral researcher, Steven Campbell, at the University of Arizona, who was working on using existing demographic data and environmental correlates to create a λ -surface, which would depict spatially-explicit rates of population change across the range, on which the presence of threats or recovery actions might act (S. Campbell, personal communication). Dr. Campbell's work estimated individual demographic rates (the population effects in the Desert Tortoise SDSS model) extrapolated to all points across the range based on capture-recapture data most often taken in more pristine areas. The working hypothesis was that the demographic rates his approach provided would represent baseline, natural tortoise demographic rates. Were the system able to estimate absolute rates, those baseline rates could be updated based on the external threats represented in the system at all locations. This would have allowed the system to calculate threat-altered values of the rate of population change (λ). While Dr. Campbell was able to generate such λ -surfaces for the desert tortoise in Nevada, unfortunately the demographic data required to construct such a surface for California were not accessible.

Estimating the absolute demographic rates based on the Desert Tortoise SDSS required *calibrating* the existing *relative* model outputs against *absolute* models of rates due to threats. Specifically it meant being able to convert the relative contributions of a threat to a population effect for a specific life stage to the corresponding demographic rate: e.g., the system being able to estimate that the threat of raven predation in an area accounts for X% of annual adult mortality in that area. The project collaborators, Dr. Bob Steidl and Erin Zylstra, began by conducting an exhaustive survey of available literature on calculating absolute demographic rates in response to threats. With this information, the project team developed four models to predict effects of several pervasive threats on rates of adult survival, juvenile survival, and reproductive output. Each model focused on a specific *mechanism* by which the threat affected the rate: for example (the threat of) "Motor Vehicles on Paved Roads" changes (the rate) of adult mortality through (the mechanism) of "Crushing" tortoises when a vehicle collides with a tortoise. Appendix B describes and documents these *absolute rate models* that model the effects of: (1) raven predation on juvenile mortality, (2) vehicle strikes on roads on adult mortality, (3) cattle grazing on adult mortality, and (4) cattle grazing on reproductive output.

Each absolute rate model predicts the part of the demographic rate that is due to a threat at a location in a formula of the form:

$$\text{Absolute demographic rate} = f(x)$$

where $f()$ is a function that predicts the demographic rate as a function of some spatial variable, x , that relates to the intensity or severity of the threat. For example, the annual mortality of adult tortoises due to crushing by cattle was estimated as:

$$f(x) = 0.001458 * x; \text{ where } x \text{ is the stocking rate in number of head per km}^2$$

Using the system's existing threat layer that depicts where cattle grazing occurs in tortoise habitat, along with estimates of stocking rates, the project team calculated the values for $f(x)$ at all points across the range, and arrived at a range-wide estimate for adult mortality due to crushing by cattle of 0.04 percent of adult tortoises.

The same approach was repeated for the other three absolute rate models, yielding a total of four spatially calculated, range-wide estimates for demographic rates due to a specific threat-to-stress mechanism (Table 4).

Table 4: Four Threat-Stress Mechanisms, Three Absolute Demographic Rates

Stress due to threat (the threat-to-stress mechanism)	Demographic rate	Relative weight of mechanism to rate in SDSS	Absolute model ID in Appendix B	Absolute demographic rate
Crushing due to Grazing	Adult Mortality	0.57%	M3.A	0.04%
Crushing due to Motor Vehicles on Paved Roads	Adult Mortality	0.94%	M2	0.11%
Predation due to Ravens	Juvenile Mortality	6.87%	M1	10.98%
Nutritional compromise due to Grazing	Change in Reproductive Output	2.41%	M3.B	-0.13%

Based on the four rate change models in Appendix B, the absolute demographic rates due to each threat-stress mechanism was calculated.

Source: Desert Tortoise SDSS, Third Iteration

For each of the four threat-to-stress mechanisms that the University of Arizona team modeled, the table above displays both the weight of the threat-stress mechanism to the corresponding population effect for the specified life stage (adult or juvenile) from the Desert Tortoise SDSS, and the estimated range-wide absolute demographic rate. Since in the system the combined weights of all threat-to-stress mechanisms that contribute to each population effect sum to 100 percent, knowing the absolute demographic rate due to one mechanism would, in theory, calibrate all contributing mechanisms to that demographic rate. Were the rates for all threats calculable, then using standard demographic modeling, the system's relative model could now calculate the actual rate of population change (λ) from threats across the landscape (Table 5).

Table 5: Absolute Demographic Rates Due to Threats

Demographic rate	# of threat-stress mechanisms in SDSS that contribute to population effect for specific cohort	# of absolute rate due to mechanism models	Absolute total demographic rate from all threats
Adult Mortality	91	2	12%
Juvenile Mortality	79	1	159%
Change in Reproductive Output	58	1	5%

Based on the one or two mechanisms calibrated for each demographic rate, the absolute demographic rate due to all threats is estimated based on all mechanisms in the Desert Tortoise SDSS that contribute to each rate.

Source: Desert Tortoise SDSS, Third Iteration

It is conceivable that only 12 percent of adult tortoises die annually due to the combined effects from the threats represented in the Desert Tortoise SDSS, in keeping with the original working hypothesis above. However, a mortality rate of 159 percent of the juvenile population is an impossible over-estimate. If there were more absolute models for individual threat-to-stress mechanisms for each demographic rate, the project partners might be able to discern whether the issue lies in the weights in the system or in individual absolute rate models.

Unfortunately, there are over 250 mechanisms by which threats can affect tortoise populations in the Desert Tortoise SDSS model. Although each of the four models of absolute demographic rates in response to threats may be valuable in and of itself, four were not sufficient to leverage the other relative weights in the system to calibrate them in terms of absolute rate estimates.

Although it was not possible to achieve the goal of calculating the absolute rate of population change (λ) from threats, this research was valuable in two important ways. First, the four absolute range-wide rate estimates were used to partially validate the relative relationships within the model. Second, the project team determined that the relative modeling approach mixes effects on demography (e.g., survival and reproduction) and carrying capacity (e.g., effects of habitat loss and habitat degradation), both of which contribute to overall population change, but in different ways.

First, adult mortality is the only demographic rate for which there is more than one absolute rate model (Table 5): namely, the two mechanisms of crushing by cattle and crushing by motor vehicles on paved roads. The ratio of the Desert Tortoise SDSS relative weights for those two mechanisms and the ratio of the corresponding rate estimates are both roughly 1:2. Given the paucity of models discussed above, this is no more than a suggestive validation, but illustrates how valuable it would have been if the literature had supported more absolute rate models for other threat-to-stress mechanisms.

Second, the project partners determined that threats on demography and threats to habitat both contribute to overall population change in different ways. Demographic effects result in almost

instantaneous changes to population numbers through adult and/or juvenile mortality or changes to reproductive output. Threats to habitat may not result in direct mortality of individuals, but changes to *carrying capacity* that result from impacts to habitat can affect population numbers. For a given region, carrying capacity is the maximum number of individuals of a particular species that resources can sustain indefinitely without significantly depleting or degrading those resources. As resources such as habitat are lost through the impacts of threats, the ability for an area to support as many tortoises is diminished. The time scale upon which such threats will act on relationships within the model may be very different than those that work through demographic effects. Considering how to handle the differences in impacts of threats to the tortoise by dividing effects into demographic effects vs. habitat effects will be a priority for the next iteration of the system.

4.2.3 Monitoring and Adaptive Management

The ranking of recovery actions by predicted effectiveness at decreasing risk to the population is the first step towards a Muticriteria Decision Analysis (MCDA) approach in which additional criteria, such as costs, funding sources, and level of public support, can be included into the prioritization (Kiker et al. 2005). Given that the Mojave desert tortoise range intersects four states, no single MCDA model will fit the heterogeneous management context. Thus, the project partners decided to focus first on creating scientific, quantitative estimates of recovery action effectiveness based solely on decreasing risk to the population. Integrating the estimates of risk to the population described in this report with a broader management MCDA model by jurisdiction would be an appropriate step in developing the next iteration of the Desert Tortoise SDSS.

The project partners developed monitoring metrics for all recovery actions in the system (Appendix C). The goal of this task was to develop metrics so that monitoring data associated with recovery action implementation and effectiveness could be collected in a way to both monitor the success of those actions and to improve the models in the Desert Tortoise SDSS to better predict the consequences of recovery actions over time. However, the large number of potential recovery/mitigation actions in any portion of the desert reflects the reality that Mojave desert tortoises are impacted by many activities of potentially greater or lesser effect. Reasonable documentation of these multiple impacts and the effectiveness of ameliorating those impacts has been elusive for reasons related to the biology of the desert tortoise, such as:

- The fact that tortoises are long-lived and many threats have chronic effects.
- Survivorship of adults is relatively high, and therefore a very slight predicted improvement in survivorship would require extensive and intensive monitoring.
- Juveniles have high mortality rates and are “cryptic:” they are camouflaged and spend time in underground burrows, making documentation of their occurrence, let alone survival, extremely difficult (USFWS 2011).

The Desert Tortoise Science Advisory Committee has advised that effectiveness of on-the-ground recovery actions for desert tortoise recovery, in general, be assessed using data from the

range-wide monitoring program. This approach emphasizes the ability to detect regional population trends rather than fine-scaled population responses to individual actions. Population abundance is an accepted metric of overall population response to both continuing threats and to successful recovery actions, which is why both Recovery Plans for the desert tortoise have included a recovery criterion calling for evidence of increasing population trends. Correlative statistical analyses that incorporate long-term desert tortoise population trends and site-specific implementation information about recovery actions will allow the estimation of what actions are most effective where. This will help improve system models to better predict the consequences of recovery actions over time.

Although the preferred method for determining recovery action effectiveness is to use regional trends of population abundance, the project team's monitoring metrics for each recovery action in the Desert Tortoise SDSS may prove useful in focused effectiveness monitoring and/or research, which was also recommended by the Desert Tortoise Science Advisory Committee. Focused effectiveness monitoring and/or research for particular actions can improve understanding of threats or actions for which greater uncertainty or controversy exists. Extremely well-designed, implemented, and coordinated research studies will be required to accurately describe recovery action effectiveness in these cases. Research requires replication and standardization of procedures, as well as effectiveness metrics that are measurable within a reasonable timeframe. The results of these experiments also will help improve system models.

4.3 Validating the Model and Data through Review

A key outcome for this California Energy Commission project is a Web-based portal with online tools, where users can upload footprints for a proposed solar energy development project and have the system estimate the increase in risk to the tortoise population from the proposed project. The user can then select a list of mitigation actions or action types to decrease the risk in the appropriate recovery unit. The U.S. Fish and Wildlife Service suggests that mitigation be conducted within the same recovery unit as the project, to benefit the same populations as are being impacted (see Figure 2 in Chapter 1).

The project partners recognize that for such a system to be useful, it must be credible to solar energy developers, scientists, regulatory agencies, land managers and other stakeholders. Feedback provided during many presentations and conversations with diverse groups convinced the project partners that users needed access to the full conceptual model and complete threats data layers, in order to evaluate and accept the science and decision analysis in the Desert Tortoise SDSS. The project partners conducted a formal review of the system conceptual model framework, and the GIS datasets used to represent each of the threats to the desert tortoise, in Spring 2012.

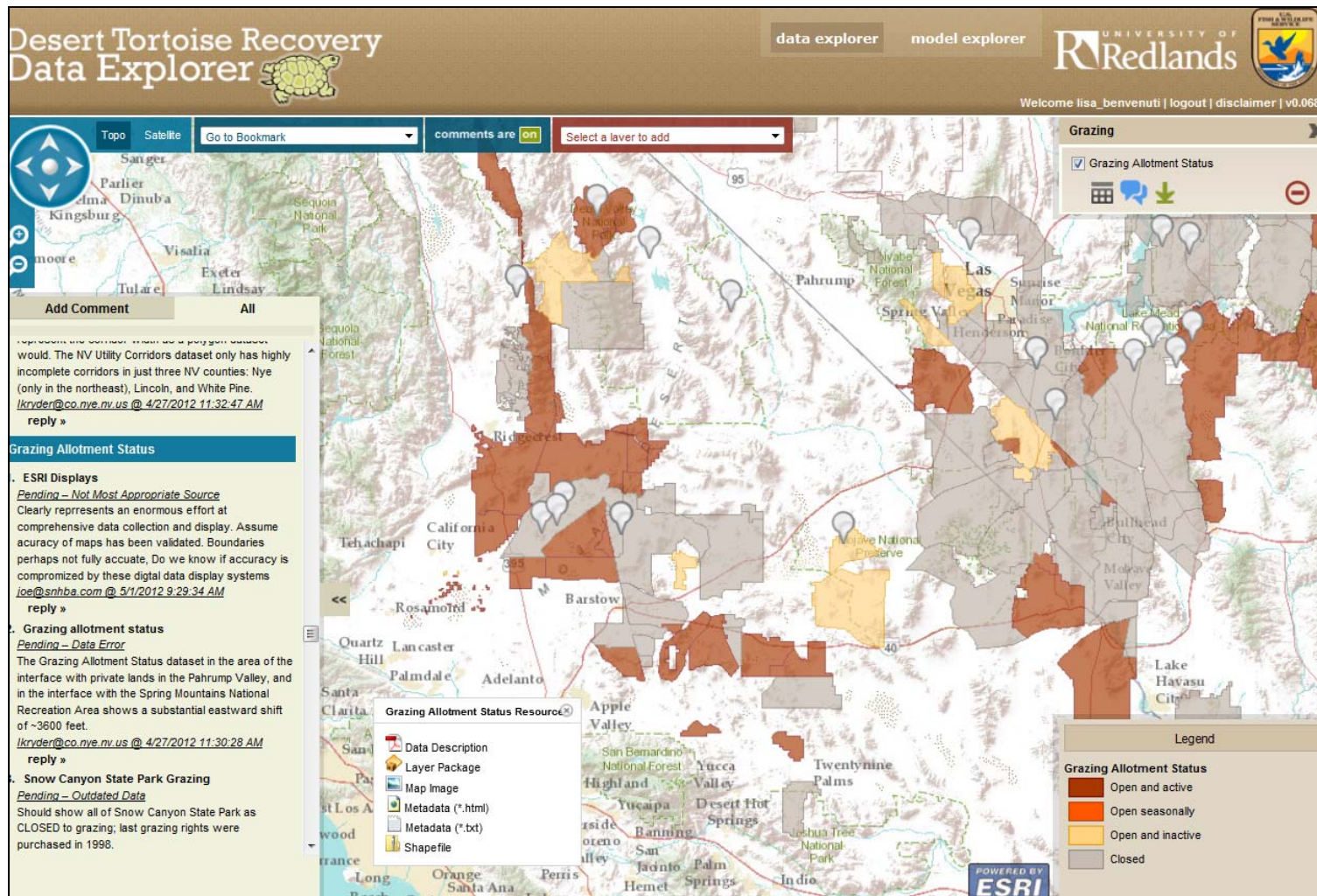
Leveraging a parallel project for the FWS, the full inventory of spatial threats datasets (using the *Data Explorer*, see below) and all aspects of the underlying conceptual model, down to the citation behind every causal relationship within the system (using the *Model Explorer*, see below) were shared with key stakeholders via the Desert Tortoise Recovery Implementation Team (RIT) process in late April and early May 2012. Desert tortoise RITs are workgroups formally

appointed by the FWS regional director in Region 8. Each workgroup is composed of managers, scientists and stakeholders from across the range of the tortoise. Forty-seven team members participated in this formal review process, which was one step in the larger RIT process (Figure 33).

4.3.1 Validating Data Using the Data Explorer

Although the project partners have acquired and manage hundreds of GIS datasets, there will never be perfect data to depict all of the threats across the entire range of the tortoise. The project partners are committed to moving forward with the best available information while continuously striving to improve datasets and models. The Desert Tortoise Recovery *Data Explorer* (available at <http://www.spatial.redlands.edu/dtro/dataexplorer>; Figure 37) was developed to provide RIT members, regulators, stakeholders, and other users with access to the source GIS datasets in the system. The goal of this site was to better inform users about how data influences system results, and therefore support better interpretation of those results in decision making. While this tool was funded by the FWS and designed specifically for the RIT process, it also plays a large role in data acquisition and validation efforts and promotes data and model transparency for this California Energy Commission project.

Figure 37: Desert Tortoise Recovery Data Explorer User Interface



This publicly available, interactive online tool can display all the datasets used for calculation in the current Desert Tortoise SDSS, and provides the user with functionality to review the metadata for the datasets and download the datasets for their own use. If the user has login credentials to the site, they can provide comments on the datasets.

Source: Desert Tortoise SDSS, Third Iteration: Data Explorer

The Data Explorer provides access to the GIS data used by the Desert Tortoise SDSS. This interactive mapping website provides features to add any of the GIS layers used by the system (unless protected by copyright) to an on-screen map through a simple dropdown list. Once the layer has been added, users can view the full attribute table for the layer to get more detail about the individual features within the layer. Documentation about the layers is downloadable as either a simple high-level summary (the *data description* in Figure 31) or as detailed Federal Geographic Data Committee (FGDC) compliant metadata (Figure 32). Users may also view and download a custom map image of the layer or download the dataset for use with their own GIS software in a number of different formats.

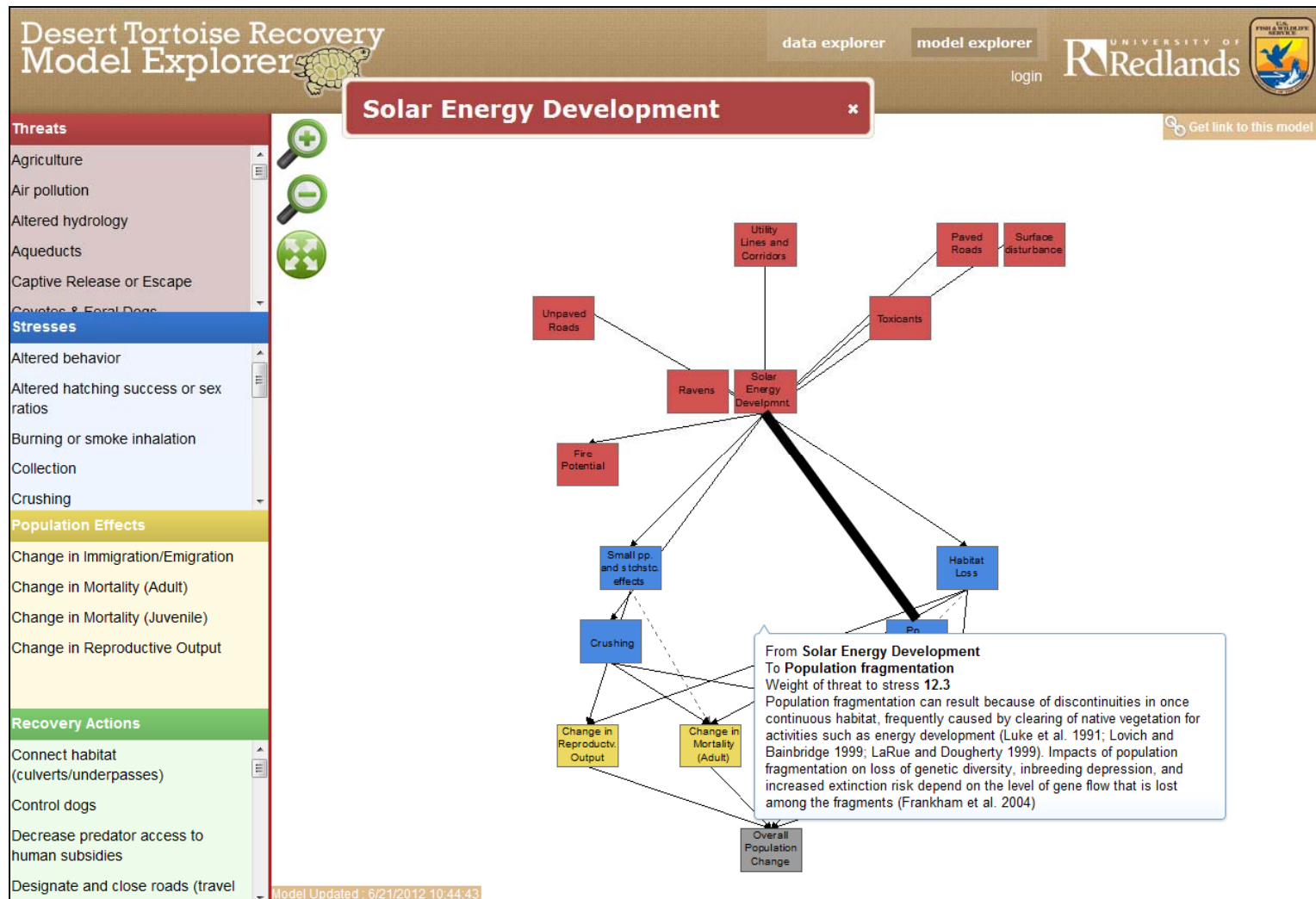
The Data Explorer also provides a location for RIT members and other authenticated users to provide feedback regarding system data. Authenticated users may use tools in a sidebar comment panel to add a comment for review by the project data team. This panel allows these authenticated users to: (1) attach the comment to a specific data layer or a general system threat or recovery action, (2) attach the comment to a specific location within the range by clicking on the map, (3) flag the data as outdated, incomplete, or missing, and (4) alert the project team that they have (or know of) better data that could be used in the system. As of December 2012, the team had received 113 comments which resulted in 30 new datasets being gathered and used within the Desert Tortoise SDSS.

The Data Explorer was developed with several different Web technologies including ASP.NET and Asynchronous JavaScript and XML (AJAX), along with both Representational State Transfer protocol (REST) and Simple Object Access Protocol (SOAP) Web services. The mapping components are built on Esri's ArcGIS® Server platform primarily utilizing their JavaScript API. A custom layer management component was required for the project team to manage and update the abundance of layers used by the Data Explorer. This ASP.NET component provides an interface for creating, updating, and deleting the layers and downloadable resources available on the site (GIS data downloads, metadata, and map images) and exposes a Web service endpoint so that the site can efficiently query for this information.

4.3.2 Validating the Conceptual Model Using the Model Explorer

The conceptual model used by the Desert Tortoise SDSS is a complex hierarchy of entities and relationships, along with critical descriptive information for each. A Web-based *Model Explorer* (<http://www.spatial.redlands.edu/dtro/modelexplorer/>) was developed under this project to provide system users with an interface to browse and explore this complex model (Figure 38). The goal for publishing this tool was similar to that for the Data Explorer: to better inform users about the conceptual model, its influence on system calculations, and the interpretation of these results in decision making.

Figure 38: Desert Tortoise Recovery Model Explorer User Interface



This publicly available, interactive online tool displays the conceptual model, or a sub-model, as in the figure, for the current Desert Tortoise SDSS, and provides the user with functionality to review the weights and citations for individual links. If the user has login credentials to the tool, they can provide comments on any element in the conceptual model.

Source: Desert Tortoise SDSS, Third Iteration: Conceptual Model Explorer

The Model Explorer allows users to become familiar with terms and relationships used by the Desert Tortoise SDSS. From this site, users can view and interact with a graphical representation of the model along with a list of model entities. Hovering over a node (individual entity) will display its system definition and clicking on a node will display a sub-model (see Figure 38), which displays how other model nodes are related to the clicked node. From the sub-model, users can hover over individual links to see why the nodes were modeled as connected and the weight of the relationship.

The Model Explorer also provides a location for authenticated users to provide feedback regarding the system conceptual model. A sidebar comment panel allows users to add a freeform comment for review by the project team, as well as alert the team to additional scientific or policy references. As of December 2012, the project partners had received 55 comments from RIT members which resulted in 10 new references implemented within the system. As well as making the modeling effort more transparent, this capability provides opportunities to continuously improve the conceptual model through broad scientist and stakeholder feedback.

4.4 Case Study: The ISEGS Test Run

In September-October 2011, the project partners collaborated with the CEC's Siting, Transmission, and Environmental Protection (STEP) Division to use the beta version of the Desert Tortoise SDSS to undertake a preliminary assessment of the desert tortoise mitigation proposed for Bright Source's Ivanpah Solar Energy Generating Station (ISEGS) project.

4.4.1 Spatial Calculations for Site-Specific Recovery Actions

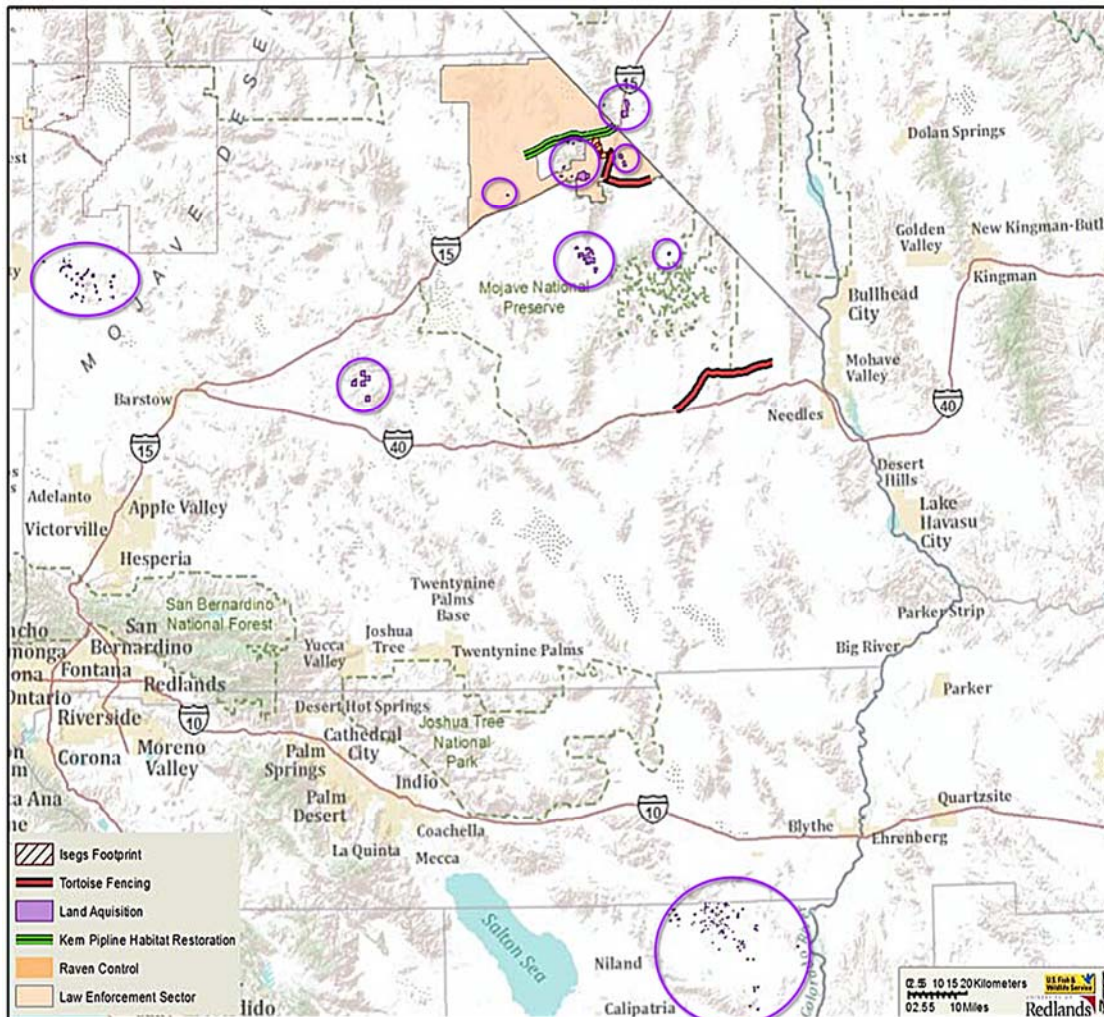
The spatial footprint for the proposed project from the STEP Division included the August 2012 footprint of the ISEGS project itself, the Yates Wells polygon of the fenced-in area, the location of the new utility line associated with the project, and the location of Colosseum Road, which the developers proposed to pave. The project partners created spatial footprints for recovery actions proposed for mitigation based on discussion with the STEP Division, BLM, and FWS, which resulted in three rounds of mitigation calculations. The final set of recovery actions proposed for mitigation included: land acquisition, raven control, increasing law enforcement, installation of tortoise barrier fencing, and tortoise habitat restoration (Figure 39).

The suite of potential, site specific recovery actions for mitigation included the following.

- Land Acquisition: Habitat compensation of ~5,185 acres within Chuckwalla/Hidden Valley
- Land Acquisition: Habitat compensation of ~3,000 acres within Fremont-Kramer
- Land Acquisition: Habitat compensation of ~8,638 acres of private land near project footprint
- Land Acquisition in Wash: State jurisdictional waters mitigation of ~160 acres

- Raven control: Decrease predator access to subsidies, such as perching or nesting sites, and food or water, within the area where the model predicts raven numbers will increase due to ISEGS
- Increase law enforcement: additional ranger in BLM Needles Field Office LE Sector 69
- Tortoise fencing: Install/maintain tortoise barrier fencing
 - singled-sided (northbound) of I-15 from Yates Well Road to Nipton Road
 - singled-sided (southbound) of I-15 from Yates Well Road to Nipton Road
 - double-sided for Nipton Road to Nipton (fencing stops at the railroad tracks)
 - single-sided (south-side) of Goffs Road, from Arrowhead Junction to Goffs
 - single-sided (north-side) of Goffs Road, from Goffs to Fenner
- Kern Pipeline Habitat Restoration: ~20.9 miles of habitat restoration

Figure 39: Spatial Extent of Recovery Actions Proposed for ISEGS 2011

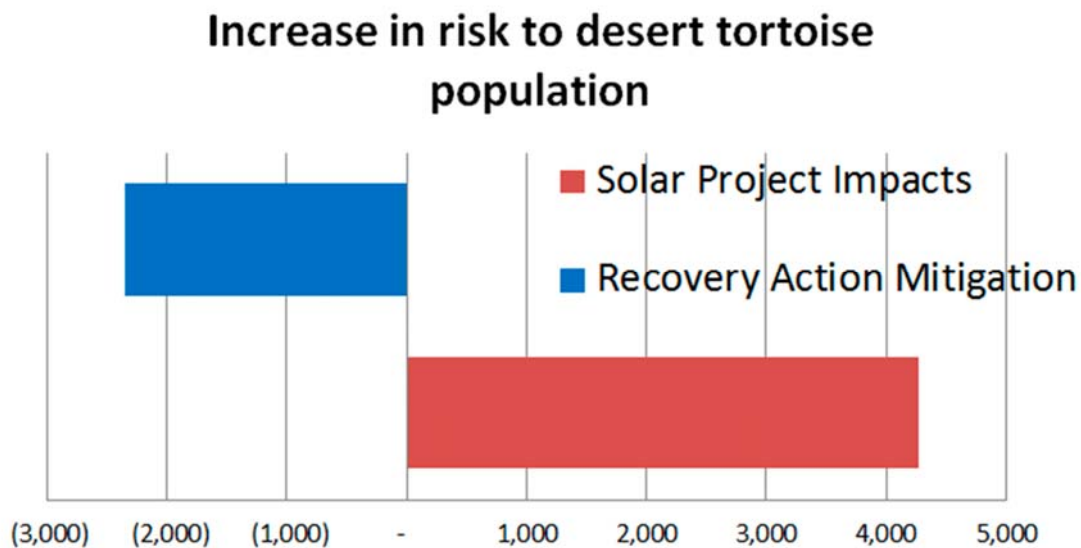


The footprint of ISEGS (three adjacent polygons in the northern middle of the map) and proposed desert tortoise mitigation actions, from the final version of the calculation described in Appendix F. For clarity, private parcels of land that were included in the mitigation suite for acquisition are circled..

Source: Desert Tortoise SDSS, Third Iteration

The system's final analyses estimated a 4,275-unit increase in risk to the tortoise population from implementation of the ISEGS project, and an estimated 2,355-unit decrease in risk from implementation of the proposed recovery actions as mitigation (Appendix F). The output numbers calculated are meaningful relative to each other and directly comparable (Figures 40 and 41). As a result of implementing both the project and the management actions, across the landscape some individual stresses will be increased, while others will be decreased to create the net change in risk to the tortoise population.

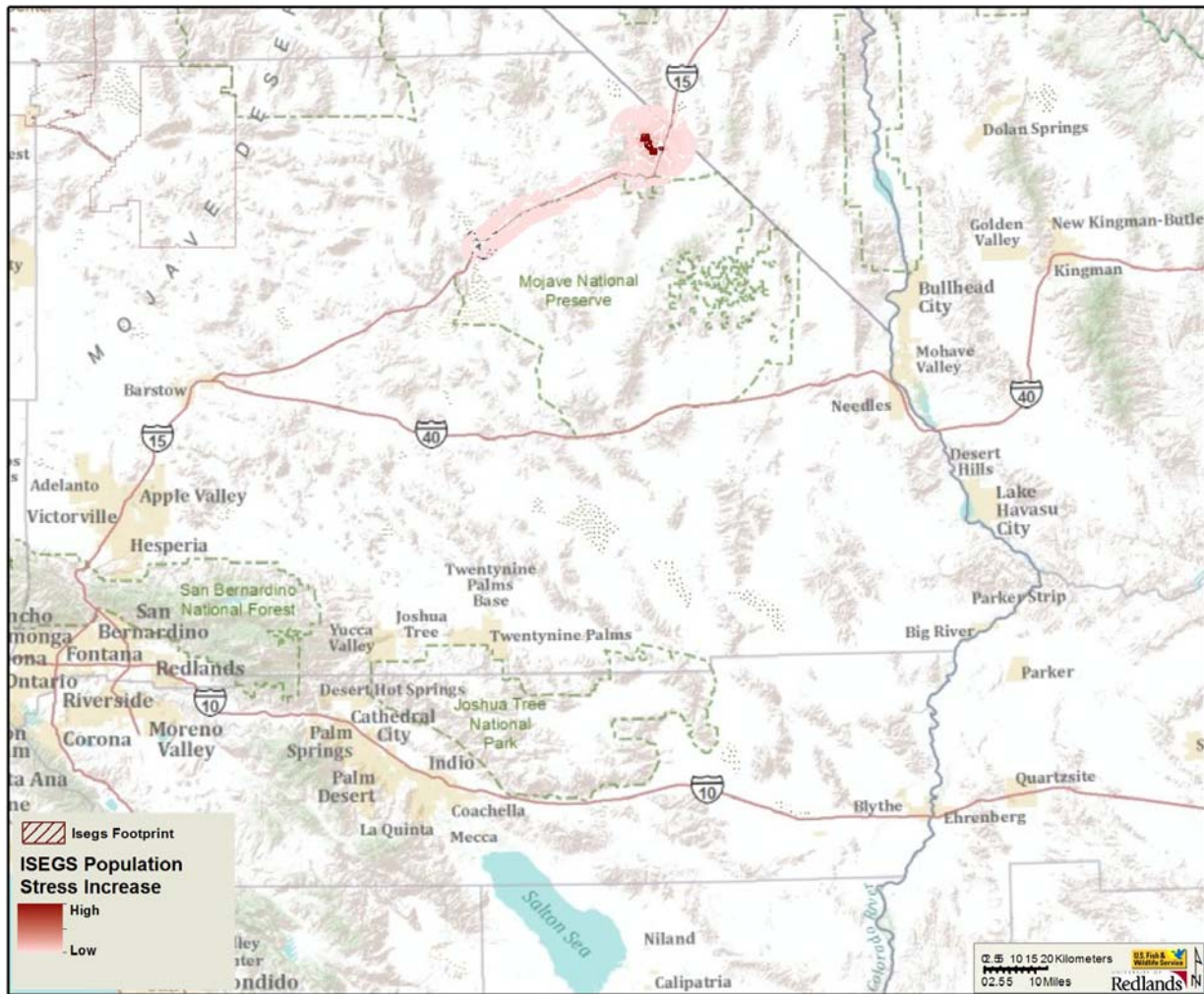
Figure 40: Change in Risk to Tortoise Population for ISEGS Solar Energy Project



Change in risk to the tortoise population based on one ISEGS proposal, and a proposed suite of recovery actions that would be implemented in the surrounding area. The August 2011 beta version of the Desert Tortoise SDSS was used together with the August 2011 ISEGS footprint.

Source: Desert Tortoise SDSS, Third Iteration

Figure 41a: Maps of Changes in Risk to the Tortoise Population



For clarity, the change in risk to the population within the study area is depicted here without the baseline stress to the tortoise: (41a) estimated increase in risk (pink-red areas) from implementation of ISEGS (increase in risk of 4,275); and (41b) estimated decrease in risk (blue-dark blue) from conducting mitigation actions (decrease in risk of 2,015).

Source: Desert Tortoise SDSS, Third Iteration

Figure 41b: Maps of Changes in Risk to the Tortoise Population



For clarity, the change in risk to the population within the study area is depicted here without the baseline stress to the tortoise: (41a) estimated increase in risk (pink-red areas) from implementation of ISEGS (increase in risk of 4,275); and (41b) estimated decrease in risk (blue-dark blue areas) from conducting mitigation actions (decrease in risk of 2,015).

Source: Desert Tortoise SDSS, Third Iteration

4.4.2 Analysis of Results

In general, the estimated amount of the direct contribution that grading an area to install a thermal solar development has on the risk to population is driven by the probability of presence in that area. Locating a project in an area with a high probability of presence will result in a relatively large direct impact. Indirect impacts from solar energy development (see Figure 25), are more determined by the weights and particular configuration of the Tier 1 direct threats such as “Toxicants”, “Fire Potential,” “Ravens” (see Figure 4 of Appendix F). “Disease” is a Tier 2 indirect threat with significant impact because “Toxicants” are such a large contributing threat to “Disease,” which itself is the only major contributor to the stress of “Toxicosis.”

When calculating the reduction in risk to population from a suite of recovery actions, those recovery actions that both have very large effects areas and significantly reduce multiple threat-stress mechanisms to stresses with large direct stress weights are the most effective; e.g., “Increase Law Enforcement,” “Install and Maintain Tortoise Barrier Fencing,” “Remove Grazing” and “Land Acquisition” (See Figure 19 above and Table 1 in Appendix F). However, “Environmental Education” is an example of a recovery action that affects many threat-stress mechanisms but in general none with large effect, so unless very well designed, its actions may produce less mitigation of population risk than expected.

4.4.3 Discussion

As with an earlier preliminary calculation for a solar energy development proposal, several discussions were required to obtain not just the initial located footprint of the ISEGS project, but also new utility lines and other associated project features connected with the indirect threats from solar energy development (Tier 1 threats in Figure 25). In the course of these dialogs, the designs themselves changed. Having developers provide project data to land managers or regulators, and then to the project team, makes for a time-consuming, inefficient dialog. A website where the regulators and/or land managers can directly input proposed solar project information, initiate computation, review results, adjust design parameters and resubmit themselves would increase the efficiency of the process. This is the intention of the new *Solar Project Impact and Mitigation Calculator* online tool created as part of this project (see Section 4.6 below).

Similarly, neither solar energy project came with a complete suite of proposed, site-specific actions for mitigation. Instead the project team worked with land managers and regulators to identify additional site-specific recovery actions in areas adjacent to the proposed projects. Access to a database of already designed site-specific recovery actions would be a valuable service to project proponents, land managers, and regulators looking to create a positive scenario for desert tortoise recovery. An initial version of this kind of recovery action database was created under this grant (see Section 4.5).

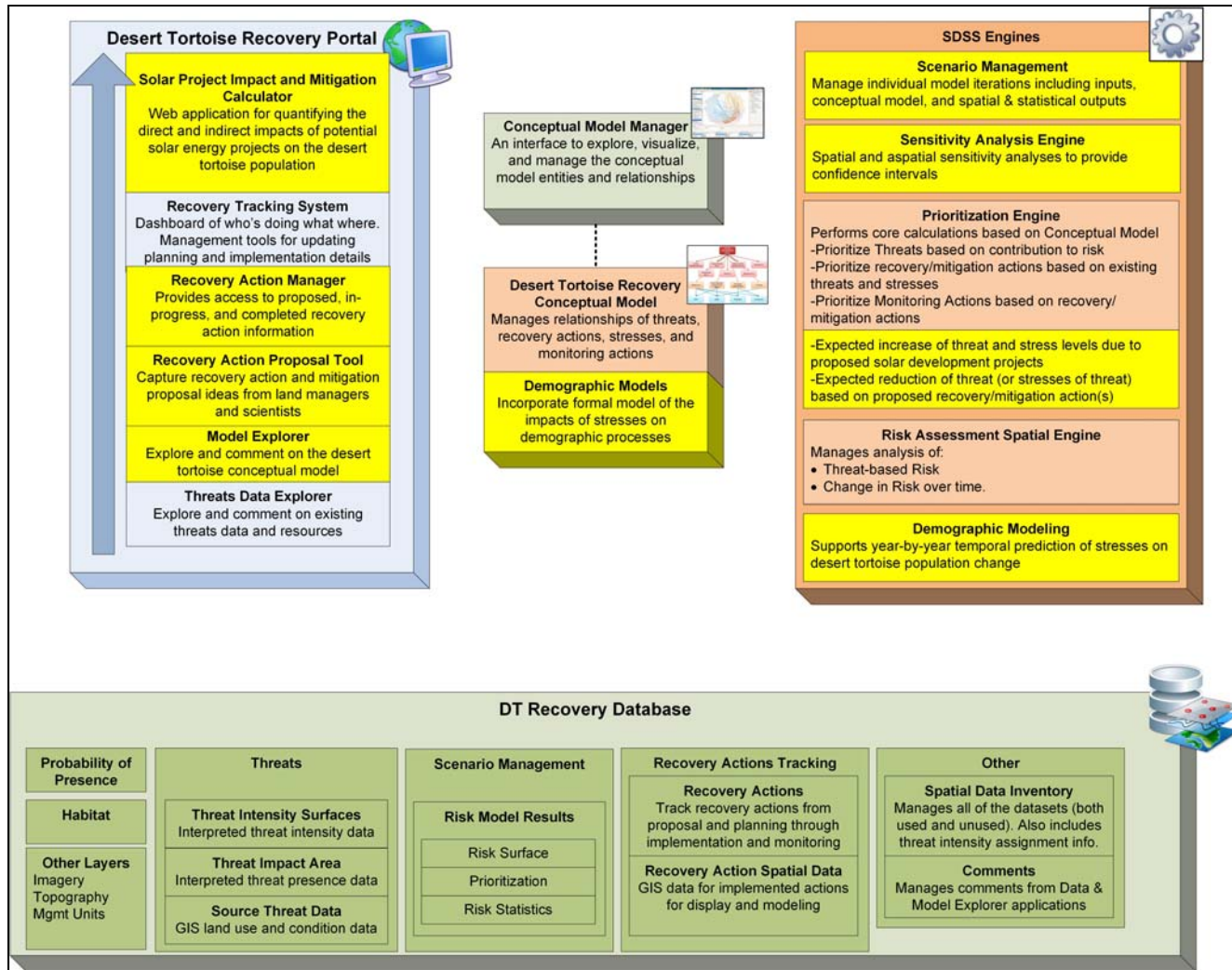
Finally, the asymmetry in the impacts of the solar project and the ameliorating effects of the recovery action suite is important. The two are spatially asymmetric (Figure 41 above) in that the impacts of the solar energy development occur mainly on the site itself, while the recovery actions are generally implemented in more pristine habitat where they can do the most benefit

to the desert tortoise. The two are also asymmetric in terms of stresses, in that the stresses that the recovery actions reduce are rarely the same stresses that the project impacts. In other words, the suite of recovery actions do not directly mitigate the impacts of the project, but they can decrease the risk to the tortoise population in other adjacent areas. The two are temporally asymmetric in that the main impacts of the solar project (habitat loss) are immediate, whereas recovery actions such as habitat restoration or environmental education, may take years to take full effect. As such, the uncertainty between the two is very different and in Section 4.7 an approach to estimating uncertainty for both impacts and offsets is described.

4.5 A Comprehensive Framework for the SDSS

The Desert Tortoise SDSS is supported by a layered services architecture that was created over the first two iterations of the system, and improved and extended under this project to support the project objectives (Figure 42). This section describes the system general architecture, and delineates those additions and improvements made during this project. Note that this section is very technical in nature, describing not only key components from this project, but also the technologies behind them. Readers may prefer to proceed to Section 4.6, where the main Web portal and its component online tools are described.

Figure 42: Desert Tortoise SDSS System Architecture



The Desert Tortoise SDSS architecture consists of four major technology stacks: database, engines, conceptual model and recovery portal. Those components of the stacks highlighted in yellow were developed under this project.

Source: Desert Tortoise SDSS, Third Iteration

The system consists of a Desert Tortoise Recovery Database component that provides services to system components, organized into three functionality stacks: Conceptual Model Manager, SDSS Engines and the online Recovery Portal. This section describes improvements made to the behind-the-scenes Database, Conceptual Model Manager and SDSS Engine components. The Web-based Desert Tortoise Recovery Portal and its component tools are described in Section 4.6.

4.5.1 Desert Tortoise Recovery Database Component

This system component stores all the data, and its many versions, used in the Desert Tortoise SDSS. All the system component stacks access this data via Web services. In the course of this project, the database schema was extended to include *scenarios*: formal versioning of the data, recovery action tracking and user comments from system component tools such as the Data Explorer and Model Explorer (see 4.5.3.2 below).

4.5.2 Desert Tortoise Recovery Conceptual Model

The conceptual model is a central orchestrating component of the Desert Tortoise SDSS that summarizes the state of the desert tortoise population change science today through a complex model of relationships. It contains key information to make the model computational and executable. It is maintained directly by desert tortoise experts using the Conceptual Model Manager (see Sections 3.2 and 4.2) and has been made available for review and comment via the Desert Tortoise Recovery Model Explorer (Section 4.3.2).

The conceptual model is technically maintained in an xml format that stores the entities, relationships, and network structure of the model. Application programming interfaces (API's) for query, network tracing, display, and analysis have been developed for Python and .NET as well as Web API's in the form of Simple Object Access Protocol (SOAP) and Representational State Transfer protocol (REST) services. These API's are used by each the various system components and engines to run analyses and/or interpret results.

4.5.3 SDSS Computational Engines

4.5.3.1 Risk Assessment Spatial Engine

The risk assessment module is responsible for performing the geoprocessing required to calculate the relative risk to the tortoise population across the landscape, generating the risk surface and statistics. This engine uses the conceptual model's Python API to query its encapsulated logic and rules to perform the required spatial operations. The module is implemented as a Python package that uses Esri's ArcPy site package for geoprocessing operations. For more information on how this threat-based risk surface is calculated, see Chapters 2 and 3.

4.5.3.2 Scenario Management

The project partners extended the model framework to include a scenario management component. This component is responsible for storing and querying a particular *scenario*: the individual input data, model configuration (nodes, links, weights, documentation, etc.), output

data, and output statistics for each individual system run over time. Each major system run has a unique scenario associated with it (its inputs and outputs). This component allows the project partners to compare results between system runs over time and even re-run a particular system version if necessary.

4.5.3.3 *Optimizing Calculations*

To support the computationally intensive spatial calculations needed for the system's threat-to-threat interactions, such as those related to solar energy development, and the thousands of model runs required for uncertainty analysis (see section 4.7), the core system engines needed at least an order of magnitude increase in calculation speed. A number of enhancements were made to the underlying system spatial calculation engine to improve performance and reliability by dramatically reducing the time required to configure and run a system iteration and by reducing the number of manual steps through data automation.

4.5.3.4 *Vector to Raster*

The first iteration of the Desert Tortoise SDSS model spatial engine was built using vector data processing. While vector processing yields the highest level of spatial precision, the required vector overlay processes resulted in system run times of several days and many memory and complex geometric and topological errors. When the model did successfully complete a run, run times were averaging nearly three days. Because of these issues and limitations, the project partners converted all datasets to raster-based processing to provide more efficient computation. This decision and an explanation of raster data and its use in the system spatial engine is described in detail in Section 4.1.5.2.

Rewriting the spatial data processing routines to use raster methods rather than vector methods was a large undertaking but once complete, provided an immediate performance enhancement. Without any further optimization of the processing routines, the required processing time dropped from several days to about 6-8 hours. After further modifications and optimization (discussed later in this section), processing time further dropped to roughly 2-3 hours per model run, with few errors.

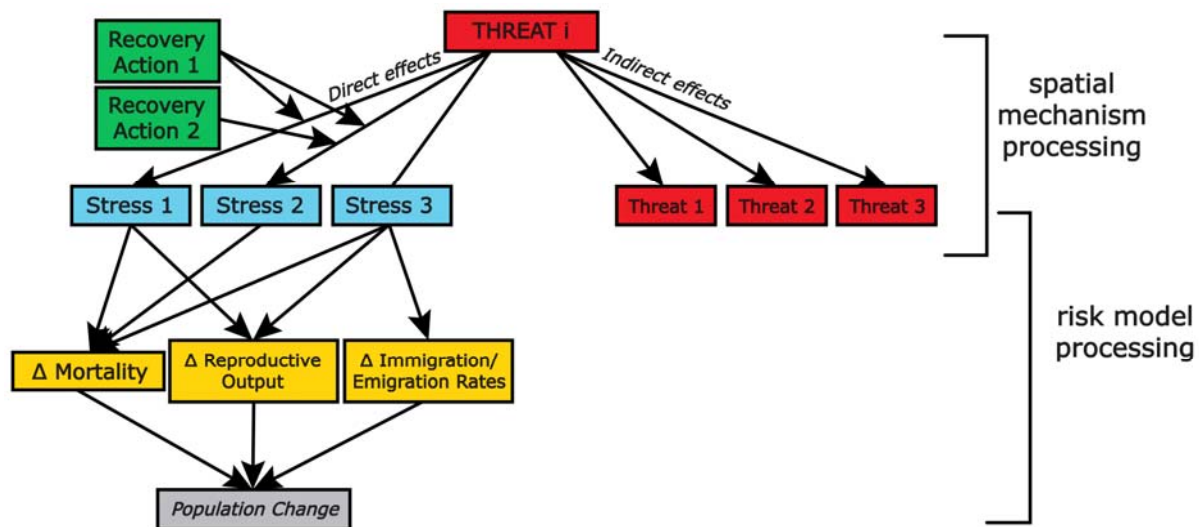
The processing routines are each written using the Python programming language and utilizing Esri's ArcPy geoprocessing framework. The Esri framework provides an extensive, robust, and supported framework for performing spatial operations of all kinds. It also provides a Web service publishing model that exposes system routines as simple http endpoints over the internet. This second point is critical for providing support to system users for performing queries and analyses through a Web browser.

4.5.3.5 *Processing Optimization*

The project team created separate modules for the system's *spatial mechanism processing* from the *risk model processing*. This allows the team to run various scenarios (versions) of the model using the same spatial data but under different model conditions (e.g., different link weights, add a relationship in the conceptual model framework, ignore a relationship, etc.). This is necessary for running Monte Carlo simulations for spatial sensitivity analysis, as discussed in Section 4.7.

The *spatial mechanism processing* entails the vector to raster data conversions, applying the probability of presence surface (Section 3.4), and any other spatial processing that is required, such as reclassification (e.g., spatial normalization, Section 2.2.3), distance decay (for generating ecological effects layers, Section 2.4.4), or density operations along with creation of a number of different summary statistics for generating reports (Figure 43). This step requires about 90 minutes to run depending on the complexity of the input data and required spatial operations.

Figure 43: Spatial Mechanism and Risk Model Processing in the Desert Tortoise SDSS



Spatial mechanism processing implements all the spatial calculations steps described in Chapters 2 and 3. Risk model processing implements all the a-spatial calculation described in Chapter 2, as well as reporting functions.

Source: Desert Tortoise SDSS, Third Iteration

The *risk model processing* then applies the weights and other rules in the conceptual model (see Section 2.4.5) to the outputs of the spatial data processing to create the final risk surfaces and summary statistics. Once the spatial mechanism processing is complete, the risk model processing requires about 1-30 minutes to complete depending on the statistics requested. Because risk model results can be created more quickly and efficiently once the spatial mechanisms have been processed, this allows execution of multiple system runs while iterating key conceptual model parameters (e.g., weighting scenarios for spatial sensitivity).

The project partners implemented a number of other modifications to the system engines to further enhance the performance of a system run. Key optimizations include:

- **Options to choose the number of output surfaces, statistics, and logging generated as output.**

The first and second system iterations created output surfaces for every node in the conceptual model along with a large number of statistical and logging outputs that were used to validate the process and results. Now that the project team is more confident with the system operations, a large number of these initial outputs have been deemed unnecessary for regular runs of the system. The creation of these outputs accounts for

the majority of the processing time, so strategically selecting which outputs are required and useful for a decision maker and generating only those dramatically reduces processing time.

- **Python Application Programming Interface (API) for reading conceptual models**

The Desert Tortoise SDSS conceptual model contains not just the description of entities and their interactions, but directives on how to compute those interactions (e.g., weights, buffer distances). When a system run is initiated, the computational engine needs to access all that information in order to faithfully execute the calculation. Previous iterations of the computational engine relied upon text table (csv) exports of the conceptual model rather than reading the model directly from the Conceptual Model Manager's files. This was an extra manual step in a system run. To automate this process, the project partners wrote an API that enables the computational engine to programmatically access the conceptual model from within the Python programming language. A .NET API and an XML-based Web API were also created to access the conceptual model.

- **Eliminating Redundant Processing.**

Previous iterations of the computational engine did not track processing steps that may end up being redundant. The engine now tracks spatial datasets and spatial operations done on the datasets to ensure that the same operation has not already occurred within the same system run for a different purpose. This redundancy would often occur when the same input dataset was used for multiple threats (e.g., the road dataset was used to represent the location of the threat of paved roads as well as the location of the threat of motor vehicles on paved roads).

4.6 The Desert Tortoise Recovery Portal

The core of the new tools and components developed under this project are accessed via the Desert Tortoise Recovery Portal.

Figure 44: Home Page of the Desert Tortoise Recovery Portal

Desert Tortoise
Recovery Portal


[LOGIN](#)


News Update: Status of the Recovery Plan

As part of the Recovery Plan development and review, the full inventory of spatial threats datasets (using the Data Explorer, see below) and all aspects of the underlying conceptual model, down to the citation behind every causal relationship within the system (using the Model Explorer, see below) were shared with key stakeholders via the Desert Tortoise Recovery Implementation Team (RIT) process in late April and early May 2012. Desert tortoise RITs are workgroups formally appointed by the FWS regional director in Region 8. Each workgroup is composed of managers, scientists and stakeholders from across the range of the tortoise. Forty-seven team members participated in this formal review process, which was one step in the larger RIT process.

Desert Tortoise News...

No new news...



Solar Project Impact and Mitigation Calculator

Use the Solar Project Impact and Mitigation Calculator to

- (1) define general information about the proposed solar energy development project,
- (2) upload or sketch the project's footprint along with any secondary features,
- (3) run impact assessment calculations, and
- (4) identify a suite of predefined recovery actions whose mitigation effects have already been individually estimated.



Recovery Action Manager

Use the recovery action manager to review recovery actions that have been proposed, fully designed or completed.



Data Explorer

Use the Data Explorer to access the GIS data used by the Desert Tortoise SDSS. In this interactive mapping tool you can add any of the GIS layers used by the system (unless protected by copyright) to an on-screen map through a simple dropdown list. Once the layer has been added, you can view the full attribute table for the layer to get more detail about the individual features within the layer. Documentation about the layers is downloadable as either a simple high-level summary or as detailed Federal Geographic Data Committee (FGDC) compliant metadata.



Model Explorer

Use the Model Explorer to become familiar with terms and relationships used by the Desert Tortoise SDSS. In this tool you can view and interact with a graphical representation of the model along with a list of model entities. Hovering over a node (individual entity) will display its system definition and clicking on a node will display a sub-model, which displays how other model nodes are related to the clicked node. From the sub-model, you can hover over individual links to see why the nodes were modeled as connected and the weight of the relationship.

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Source: Desert Tortoise SDSS, Third Iteration: Desert Tortoise Recovery Portal

Users must log into the Portal (Figure 44), but once they are authenticated they can access the four tools to help them use the system for solar energy project impact and recovery action mitigation calculations (Table 6).

Table 6: Components in the Desert Tortoise Recovery Portal

Component	Purpose of the Component	Access
Recovery Action Manager	Manages and tracks proposed, designed and implemented recovery actions	Authenticated users only
Solar Project Impact and Mitigation Calculator	Users can enter new solar energy development project information, select mitigating recovery actions and run risk offset calculations	Authenticated users only
Model Explorer	Explore and comment on Conceptual Model used in the system	Public, and authenticated users can comment
Data Explorer	Explore and comment on spatial datasets used in the system	Public, and authenticated users can comment

Source: Desert Tortoise SDSS, Third Iteration

Relevant updates and event information is shown on the right (Figure 44), and the tools are listed on the home page, and always available via the toolbar at the top of the page. Clicking on any of the tool links launches that tool with the user authentication already in place. The Data Explorer and Model Explorer have already been described in Section 4.3 and are not discussed further in this section. One advantage of launching these tools from the Portal is that the user is already logged in and can access the commenting function, if desired.

4.6.1 Recovery Action Manager

As part of the FWS-sponsored RIT process (Section 4.3 and Figure 33), managers, stakeholders and scientists proposed and prioritized recovery actions that may be implemented by various agencies and/or used as mitigation for potential solar energy development projects. The project partners created online tools as part of the Desert Tortoise SDSS to enable developers and land managers to leverage these and other “banked” recovery actions as the starting point for suggesting site-specific recovery actions as mitigation for the impacts from proposed solar energy development projects.

The RIT recovery action proposals were gathered using a tool developed in this project called the *Recovery Action Proposal Tool*. This online tool allowed participants to propose recovery actions for specific tortoise conservation areas and workgroup areas. In the summer of 2012, RIT participants entered 1186 proposed recovery actions. Those proposed actions were a starting point for RIT participants who, in a series of range-wide workshops in the fall of 2012 (Figure 33), refined and prioritized a set of recovery actions. These prioritized actions are the RIT’s

advisory recommendations to the U.S. Fish and Wildlife Service for what the group agreed to as the highest priority actions to be taken over the next five years. These advisory recommendations can be taken into consideration as site-specific actions are developed by land and wildlife management agencies for implementation as mitigation or otherwise.

The project team extended the database framework to include the recovery actions proposed, refined and prioritized by the RIT members during the recovery action planning process (Spring – Fall 2012). The team imported additional site-specific recovery actions contributed by land managers and others in the course of solar energy impact and mitigation calculations. Over 800 area-specific proposals were uploaded from the RIT workgroups alone. Ultimately these proposed recovery action will be available to the Solar Project Impacts and Mitigation Calculator so that developers and land managers can select from this “bank” a suite of recovery actions as potential mitigation for a specific solar energy development project.

4.6.2 A Walkthrough of the Recovery Action Manager


The *Recovery Action Manager* is the first phase of an online tool to manage pre-designed recovery actions, make them available for mitigation, and track their implementation.

4.6.2.1 *Recovery Action Manager Home Page*

On the main page of this online tool (Figure 45), users may access all of the recovery actions that have been provided to date. Recovery actions are broken down by: (1) workgroup regions (as defined by the RIT process), (2) tortoise conservation areas, and (3) the Action Status field, which can have values of Proposed, In Progress, and Completed. Each recovery action is displayed with its complete description, identifying information for reference, source (e.g., RIT, BLM), Action Status, and a link to an Action Details page (Figure 46).

Figure 45: Recovery Action Manager

Desert Tortoise Recovery Action Manager



[Recovery Action Portal](#)
[data explorer](#)
[model explorer](#)

Welcome testAdmin | [Logout](#)

Use this tool to manage, review, and in the future, to refine designs of specific recovery actions. The Recovery actions are broken down by: (1) workgroup regions (as defined by the RIT process), (2) tortoise conservation areas, and (3) the Action Status field, which can have values of Proposed, In Progress, and Completed. Each recovery action is displayed with its complete description, identifying information for reference, source (e.g., RIT, BLM), Action Status, and a link to the Action Details page.

You are a member of multiple workgroups. Please select a workgroup:

[West Mojave](#)
[Upper Virgin River](#)
[Northeast California Mojave](#)
[Utah/Arizona](#)
[Southwest Nevada](#)
[Colorado Desert](#)
[Southeast Nevada](#)

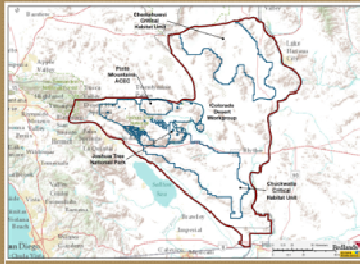
Workgroup: Colorado Desert

[Show All Actions](#)


Filter By


- Chemehuevi (Critical Habitat Unit)
- Chuckwalla (Critical Habitat Unit)
- Joshua Tree National Park
- Pinto Mountains (ACEC)
- Outside Conservation Areas


Actions that apply to the entire Workgroup region



Action Status


Proposed


InProgress


Complete



Proposed Actions (77)

SDS ID : 1	<p>Develop an invasive plant species management plan for the desert tortoise habitat within the Colorado Desert recovery unit (e.g. Sahara mustard, Buffel grass)</p> <p>See Action Details</p> <p>Actions listed in report areas : Chemehuevi (CHU) in Colorado Desert Workgroup; Chuckwalla (CHU) in Colorado Desert Workgroup; Pinto Mountains (Tortoise ACEC) in Colorado Desert Workgroup; Joshua Tree National Park in Colorado Desert Workgroup; Outside Conservation Areas in Colorado Desert Workgroup;</p> <p>Recovery Action Types : Restore Habitat</p> <p>SDS Action ID : 1</p> <p>Submitted : 10/16/2012</p> <p>Source : RIT</p> <p>4 Comments View Comments</p>
SDS ID : 2	<p>Ensure that Riverside, San Bernardino, and Imperial county, utility, transportation workers (e.g. maintenance railroad/roads crews) have desert tortoise awareness training.</p> <p>See Action Details</p> <p>Actions listed in report areas : Chemehuevi (CHU) in Colorado Desert Workgroup; Chuckwalla (CHU) in Colorado Desert Workgroup; Pinto Mountains (Tortoise ACEC) in Colorado Desert Workgroup; Joshua Tree National Park in Colorado Desert Workgroup; Outside Conservation Areas in Colorado Desert Workgroup;</p> <p>Recovery Action Types : Fire management planning and implementation</p> <p>SDS Action ID : 2</p> <p>Submitted : 10/16/2012</p> <p>Source : RIT</p> <p>2 Comments View Comments</p>
SDS ID : 3	<p>Work with utility companies to retrofit existing transmission infrastructure to eliminate a vian predator subsidies. For new transmission, recommend co-location of facilities, underground lines should be prioritized, and remote lines should be discouraged to the maximum extent.</p> <p>See Action Details</p> <p>Actions listed in report areas : Chemehuevi (CHU) in Colorado Desert Workgroup; Chuckwalla (CHU) in Colorado Desert Workgroup; Pinto Mountains (Tortoise ACEC) in Colorado Desert Workgroup; Joshua Tree National Park in Colorado Desert Workgroup; Outside Conservation Areas in Colorado Desert Workgroup;</p> <p>Recovery Action Types : Withdraw mining</p> <p>SDS Action ID : 3</p> <p>Submitted : 10/16/2012</p> <p>Source : RIT</p> <p>3 Comments View Comments</p>

Home page of the Recovery Action Manager showing all predefined recovery actions for the selected workgroup area. This list is broken down by Action Status.

Source: Desert Tortoise SDSS, Third Iteration: Recovery Action Manager

Figure 46: Recovery Action Manager: Details Page



The Action Details page of the Recovery Action Manager. As well as providing a view of the details of that Recovery Action, the page also provides functionality to view and add comments.

Source: Desert Tortoise SDSS, Third Iteration: Recovery Action Manager

4.6.2.2 Discussion

The Recovery Action Manager tool is intended to be used by land or wildlife managers and scientists to propose and locate recovery actions, and track their implementation. Web services have also been developed to make those stored, proposed recovery actions available to the Solar Project Impact and Mitigation Calculator (Section 4.6.4 below). In the future, the project team envisions incorporating the functionality of the Recovery Action Proposal Tool into the Recovery Action Manager Tool, so users can add recovery action proposals as well as review existing ones. In addition, the team plans to develop recovery action editing tools that will support users in refining proposed designs.

By delivering this level of access, transparency, and participation, the project partners hope to keep the recovery actions database current, relevant, and populated with site specific recovery actions that, according to current knowledge, represent the most effective and appropriate actions possible to recover the species population and habitat.

4.6.3 The Solar Project Impact and Mitigation Calculator

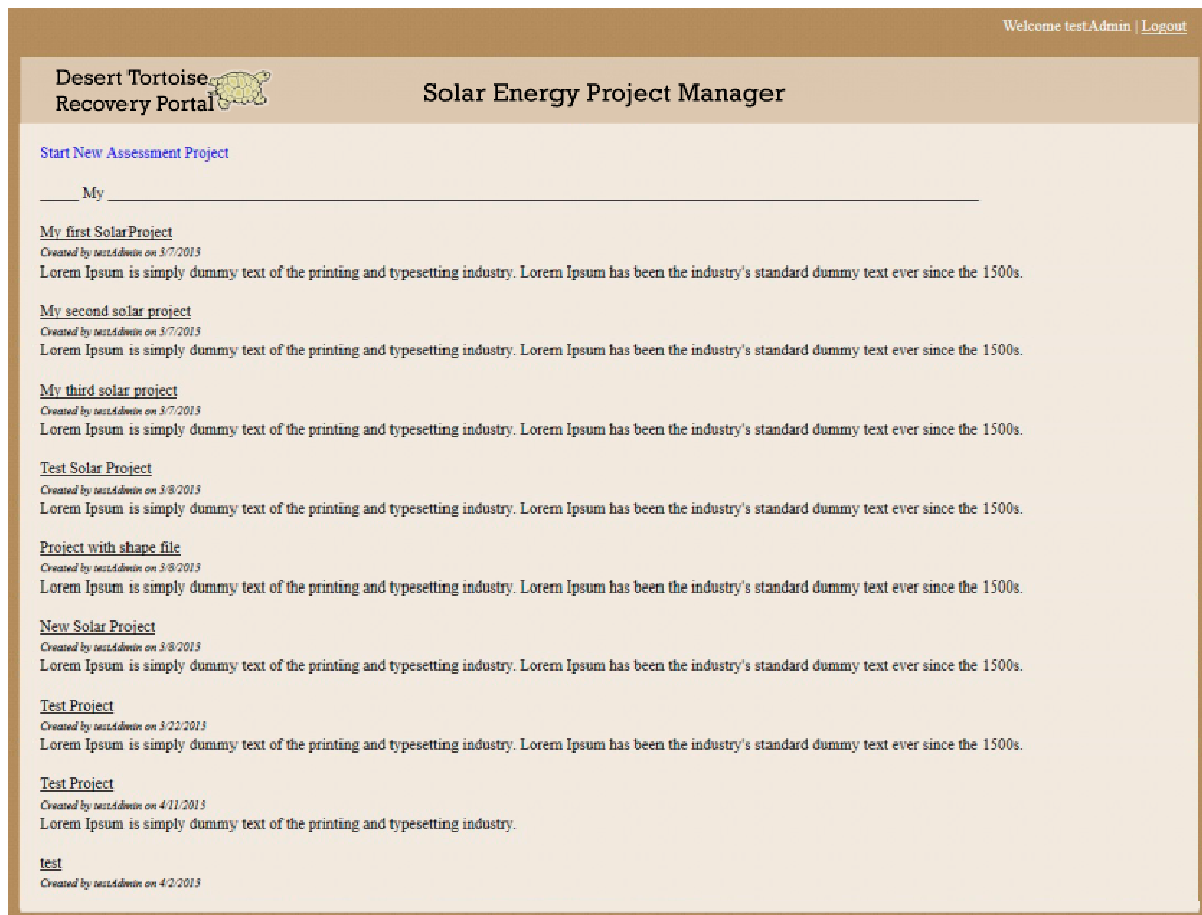
Because of the complex components and calculations that make up the Desert Tortoise SDSS, coordinating and managing a full solar project impact assessment, along with identifying ready-to-calculate mitigating recovery actions, can be a long and arduous process. As discussed in the ISEGS case study, this required a back-and-forth dialog among project proponents, managers, regulators and the project team to: (1) discuss inputs such as the project boundaries and additional feature locations such as power lines and additional roads with their own tortoise impacts, and (2) discuss calculation outputs and then revise, and rerun if necessary. In parallel, not all recovery actions in the initial suite of proposed actions may be sufficiently spatially specific for the system to calculate a risk mitigation score for them, which requires further back-and-forth communications. The team has designed and developed this online tool to simplify and streamline this process into a common workflow that can be run directly by agencies, project proponents, scientists, or other interested parties.

Using the *Solar Project Impact and Mitigation Calculator*, an authenticated user can: (1) define general information about the proposed solar energy development project, (2) upload or sketch the project's footprint along with any secondary features, (3) be provided with impact assessment results similar to those created manually by the project team for previous case studies, and (4) be supported in identifying a suite of predefined recovery actions whose mitigation effects have already been individually estimated.

4.6.4 A Walkthrough of the Solar Project Impact and Mitigation Calculator

This tool allows for the creation and management of multiple solar projects through the Assessment Project Management page (Figure 47). From this page, users can start a new assessment project, see descriptive information about each of their individual projects, and link to the assessment dashboard page to review, revise, and/or rerun an assessment. They can also select a suite of recovery actions from the database of proposed actions and compare the estimated mitigation of those actions to the solar energy project's impact.

Figure 47: Assessment Project Management Page



Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

A user would start the process of setting up a new solar project by clicking the “Start New Assessment Project” link (Figure 48).

Figure 48: Start New Assessment Project Page

The screenshot shows the 'Start New Assessment Project' page in the Solar Energy Project Manager. The page has a header with the 'Desert Tortoise Recovery Portal' logo and the title 'Solar Energy Project Manager'. A user is logged in as 'testAdmin'. The main content area on the left lists several projects, each with a title, creation date, and a brief description. A modal window titled 'Start New Project' is open in the center, allowing the user to enter project details. The modal has two text input fields: 'ProjectName' and 'Description'. The 'ProjectName' field contains the text 'First Solar Stateline Solar Energy Development.' and the 'Description' field contains the text 'First Solar, is developing a 300 megawatt (MW) PV solar farm in eastern San Bernardino County, California. When fully'. At the bottom of the modal are two buttons: 'Start' and 'Done'.

Start New Assessment Project

My

My first SolarProject
Created by testAdmin on 3/7/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

My second solar project
Created by testAdmin on 3/7/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

My third solar project
Created by testAdmin on 3/7/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

Test Solar Project
Created by testAdmin on 3/8/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

Project with shape file
Created by testAdmin on 3/8/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

New Solar Project
Created by testAdmin on 3/8/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

Test Project
Created by testAdmin on 3/22/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s.

Test Project
Created by testAdmin on 4/11/2013
Lorem Ipsum is simply dummy text of the printing and typesetting industry.

test
Created by testAdmin on 4/2/2013

Start New Project

ProjectName
First Solar Stateline Solar Energy Development.

Description
First Solar, is developing a 300 megawatt (MW) PV solar farm in eastern San Bernardino County, California. When fully

Start Done

Entering the basic information for a new Solar Project Assessment. User identity information is appended automatically from when they logged into the portal.

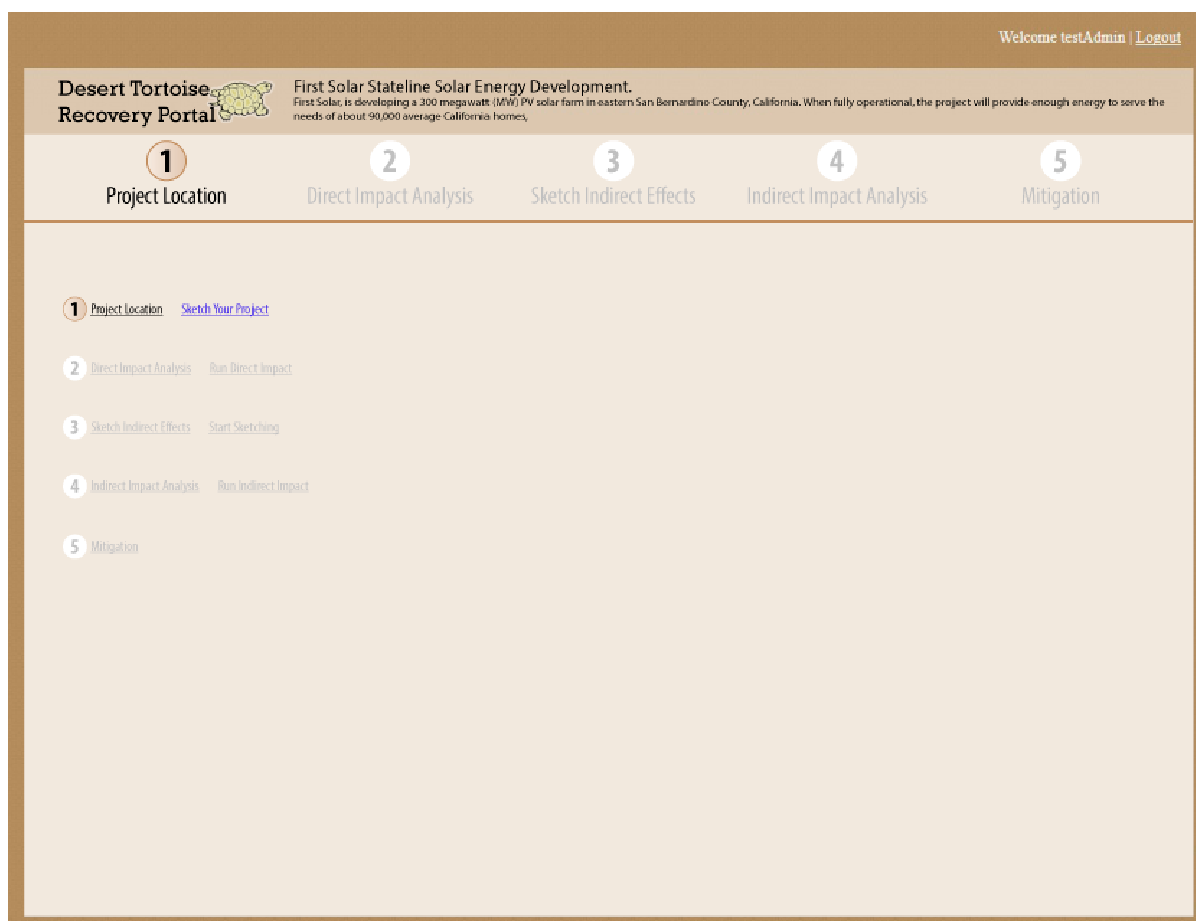
Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

Once basic description information has been entered, the tool walks the user through the analysis workflow in five steps, each of which may be adjusted and rerun as necessary:

- (1) Project Location
- (2) Direct Impact Analysis
- (3) Indirect Effect Locations
- (4) Indirect Impact Analysis
- (5) Mitigation

The Project Assessment Dashboard is designed to be a live report that expands as the user walks through each of the steps in the analysis (Figure 49).

Figure 49: Project Assessment Dashboard



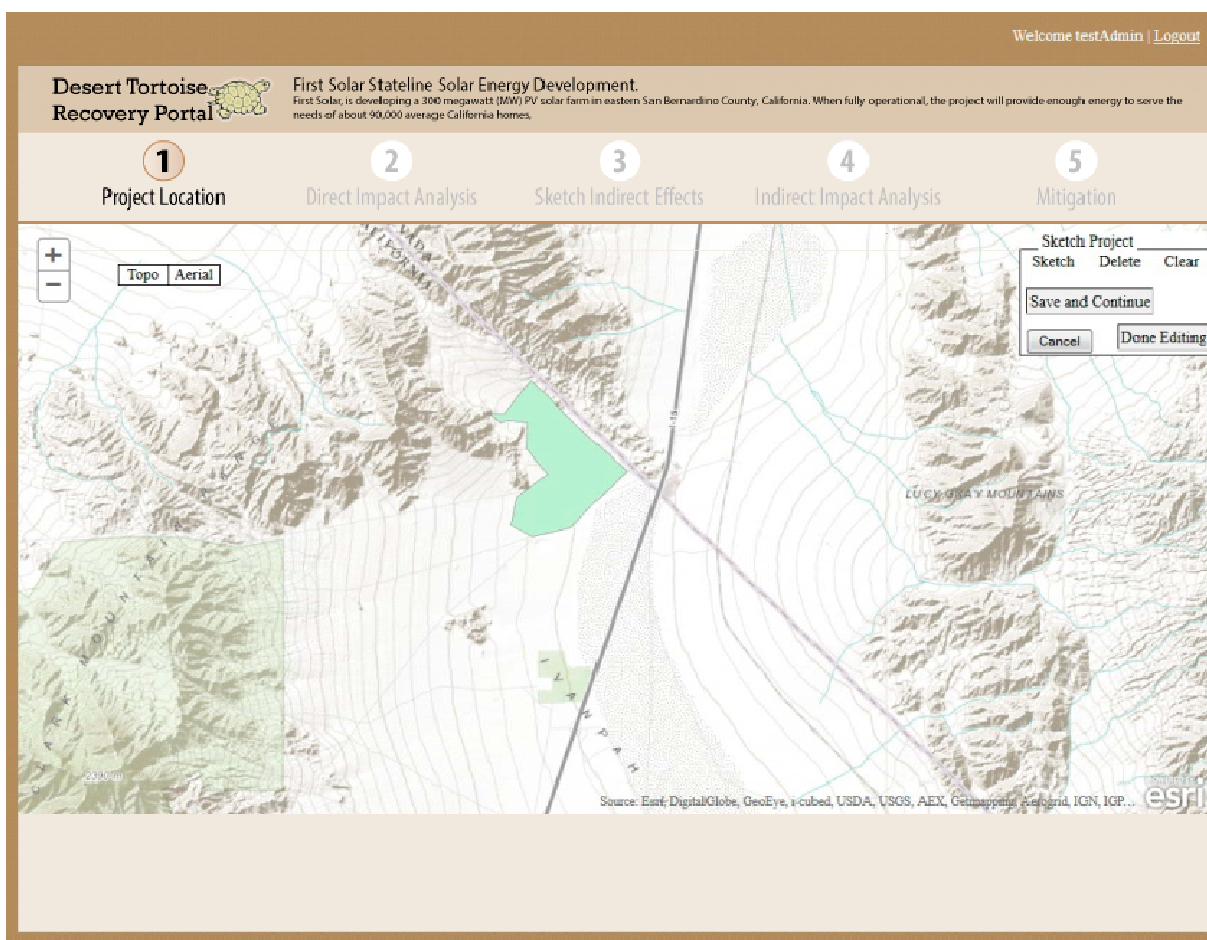
The Solar Energy Project Assessment Dashboard is the main page area with the five steps running vertically down it. As the user completes the steps in the process, the dashboard fills out with results from each step.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

4.6.4.1 Analysis Step 1: Project Location

The first step in the process is to define the project location and footprint. An interactive map is provided with simple sketching tools for drawing the project boundary. Users may draw new polygons, click and modify existing polygons (add, move, delete vertices), delete existing polygons, or clear the entire sketch. Alternatively, an existing shapefile of the project footprint may be uploaded (Figure 50).

Figure 50: Sketching Tool for Project Footprint in Step 1: Project Location

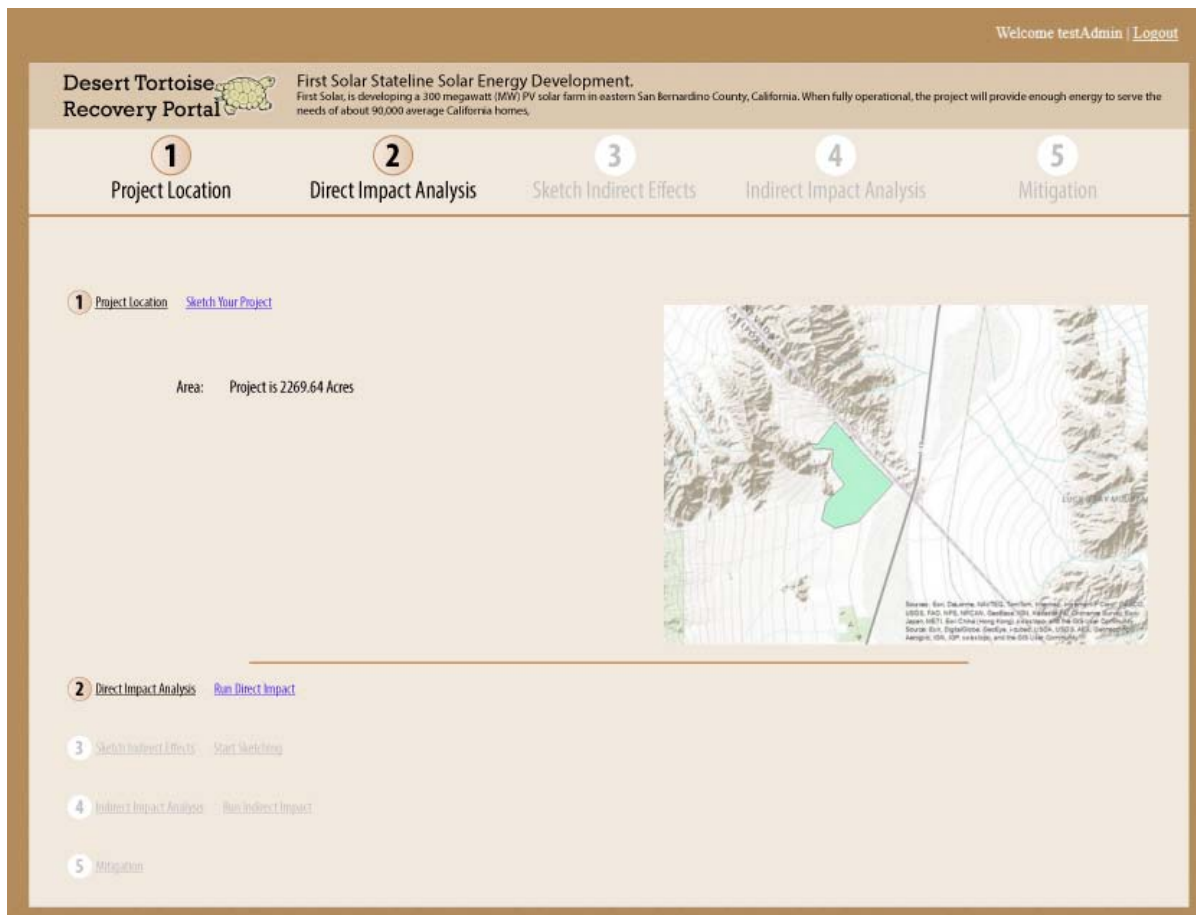


A sketching tool for creating the footprint of the solar plant on the map. This is Step 1 of the Assessment process.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

Once the project location has been defined, a map is displayed on the project dashboard. Some size and location information is also automatically generated and displayed on the dashboard (Figure 51).

Figure 51: Dashboard with Step 1: Project Location



The outcome of Step 1, the creation of the solar project's footprints, are added to the Assessment Dashboard.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

4.6.4.2 Analysis Step 2: Direct Impact Analysis

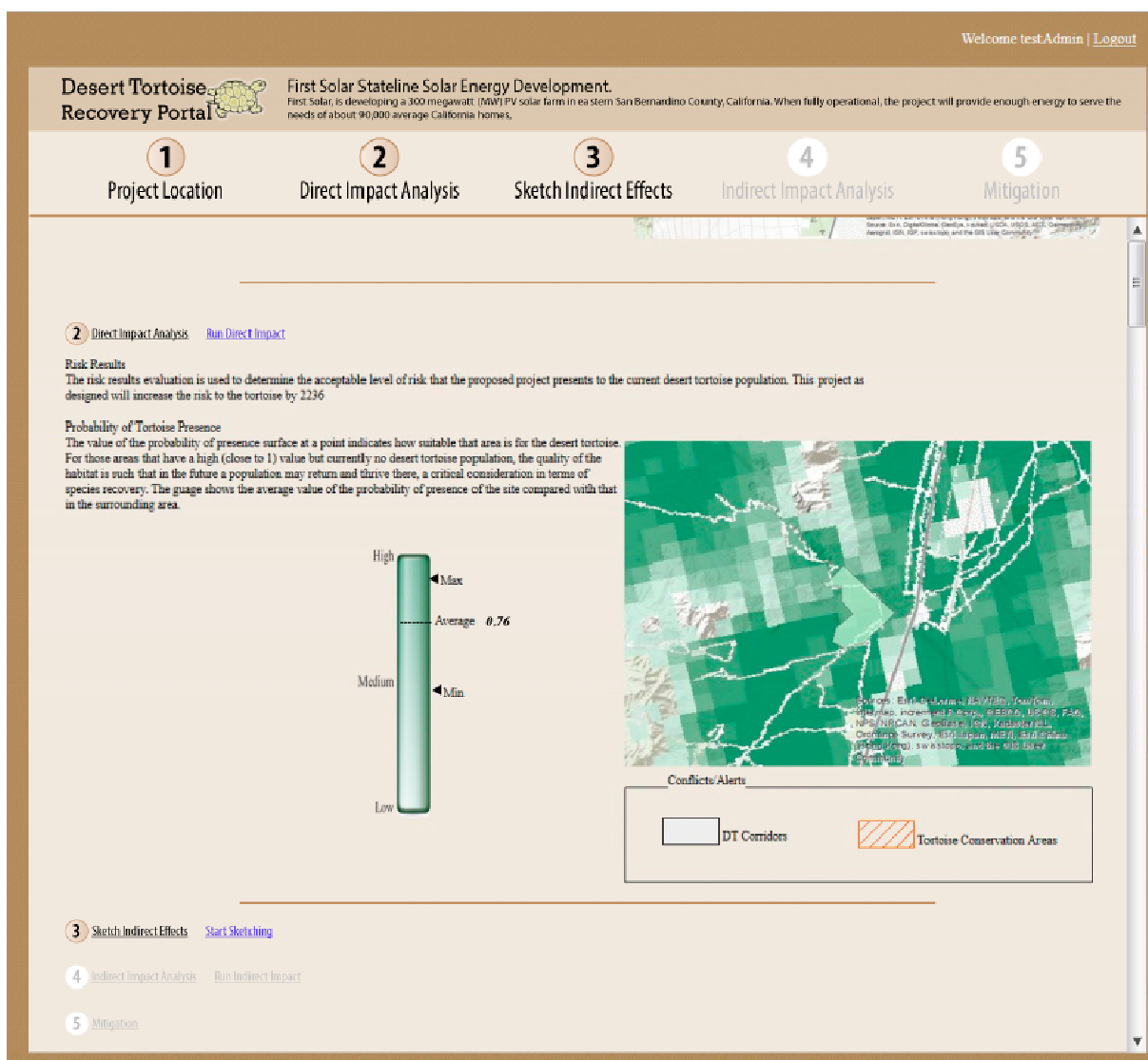
Due to the processing time required to run a full impact calculation, the full analysis is separated into a *Direct Impact Analysis* and an *Indirect Impact Analysis*. The *Direct Impact Analysis* calculates the expected increase in risk to the tortoise population due directly to habitat loss, potential crushing of tortoises, and population fragmentation within the solar project footprint, while ignoring the secondary impacts defined in the model (Tier 2 and above in Figure 25). The increase in risk value calculated based on the direct impact generally accounts for 70-90 percent of the total estimated increase in risk to the population. The direct impact analysis can be run relatively quickly and provide near-instant feedback to the user. So, while this direct impact calculation does not provide the complete picture of the impacts, it provides useful preliminary results for project assessment.

After a few seconds to run the direct impact calculation, the results are appended to the dashboard. These results are displayed in two sections: *Risk Results* and *Probability of Presence*

Results. The Risk Results section displays the estimate of how much the risk to the population would increase based on the direct impacts of the solar energy project.

Because probability of desert tortoise presence is the primary factor for the direct impact calculation, the tool displays these results in a separate section. To highlight the proximity of the project to critical tortoise resources, this section provides a map of the project footprint and current probability of presence overlaid with tortoise conservation areas and identified habitat corridors. A chart of the range of probability of presence values (0-1) is also displayed for reference (Figure 52).

Figure 52: Dashboard with Step 2: Direct Impacts Analysis



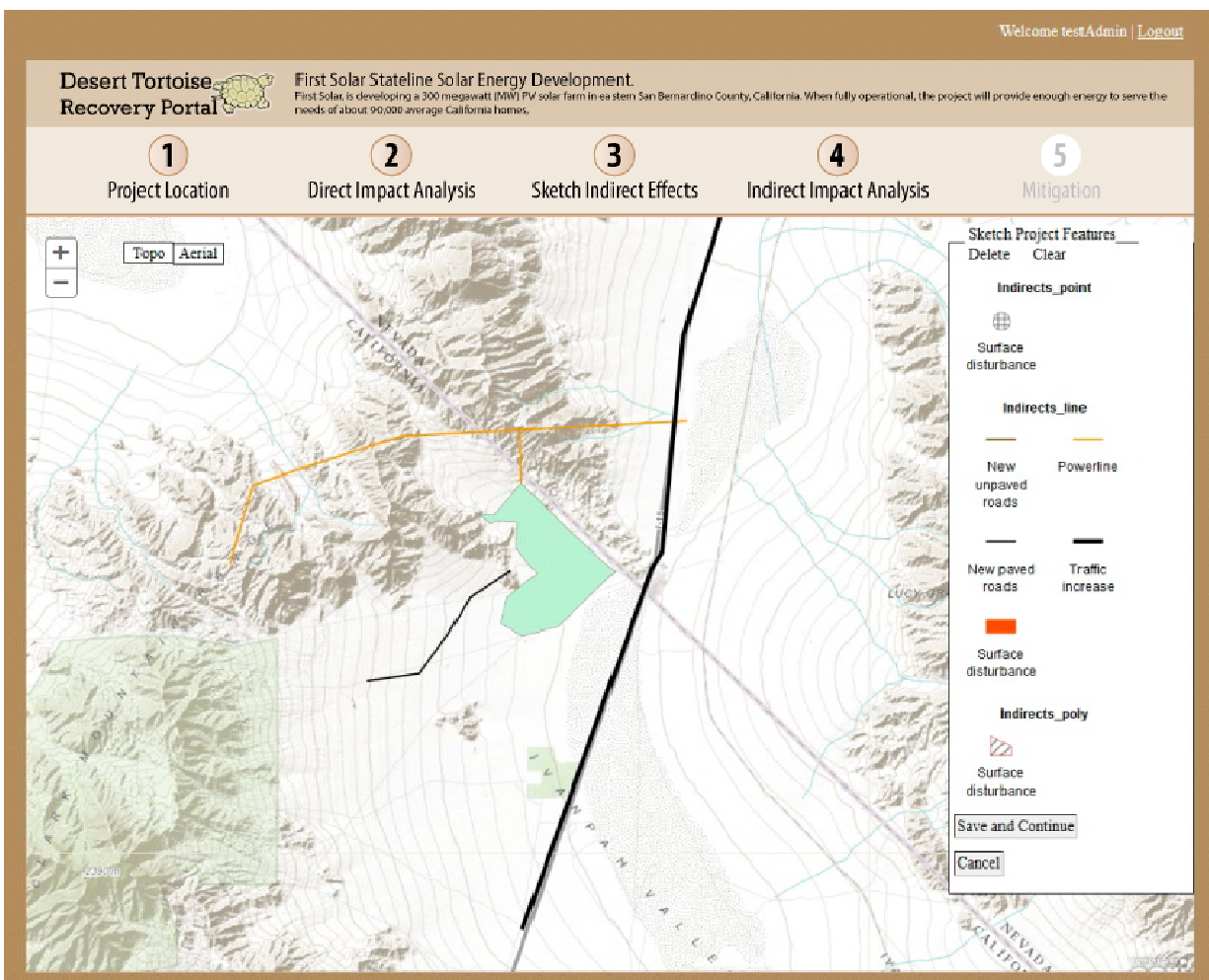
The outcomes of Step 2: Direct Impact Analysis are shown on the Assessment Dashboard.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

4.6.4.3 Analysis Step 3: Indirect Effect Locations

The system calculates the *Indirect Impact Analysis* based on corollary threat weights and spatial relationships as discussed in Section 3.3.2. While the system attempts to predict areas where new and increased corollary threats may be found as part of this calculation, the risk estimates are greatly enhanced when the location of some of these features are explicitly input into the system. These features are generally ones that a project designer would be planning related to the project, such as new paved and unpaved roads, new utility lines, additional areas of surface disturbance, etc. Because of this, the project planner would be asked to provide location-specific details for these features. This online tool also provides an interface for inputting these features by sketching them on the map. The user may select from a “palette” of the expected features and sketch them on the map, as well as edit and delete existing features on the map (Figure 53).

Figure 53: Map Sketching Tool for Project Design in Step 3: Indirect Effect Locations

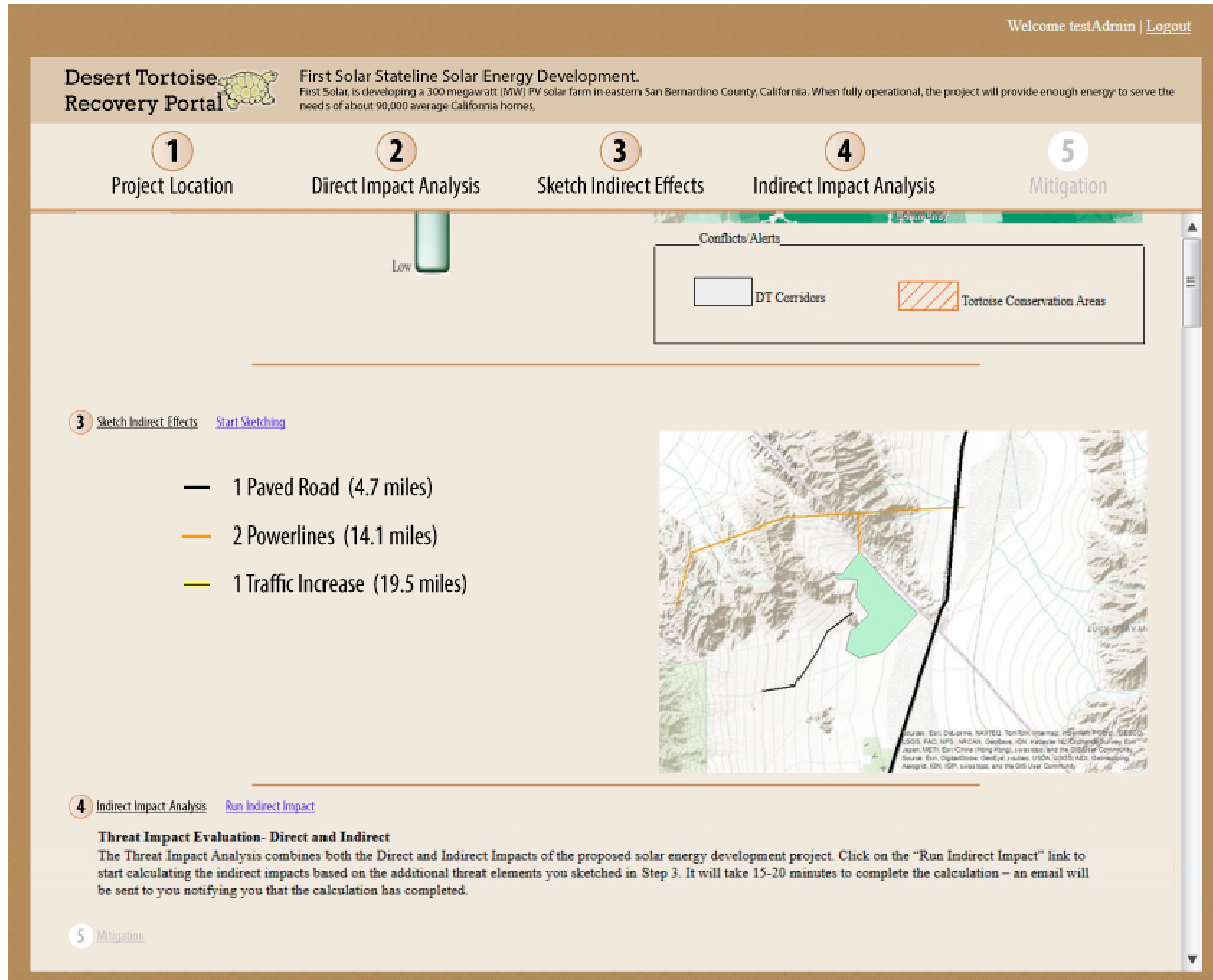


The map sketching tool for a project designer to depict where additional designed elements of the solar project such as access roads, utility lines, and additional areas where the surface will be disturbed such as staging areas, will be located.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

Once these features have been sketched and saved, the tool displays a map on the project dashboard along with some general feature count and size information that is automatically generated and displayed (Figure 54).

Figure 54: Dashboard with Step 3: Indirect Effect Locations



The outcome of Step 3: the location of additional design features associated with indirect threats from solar energy.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

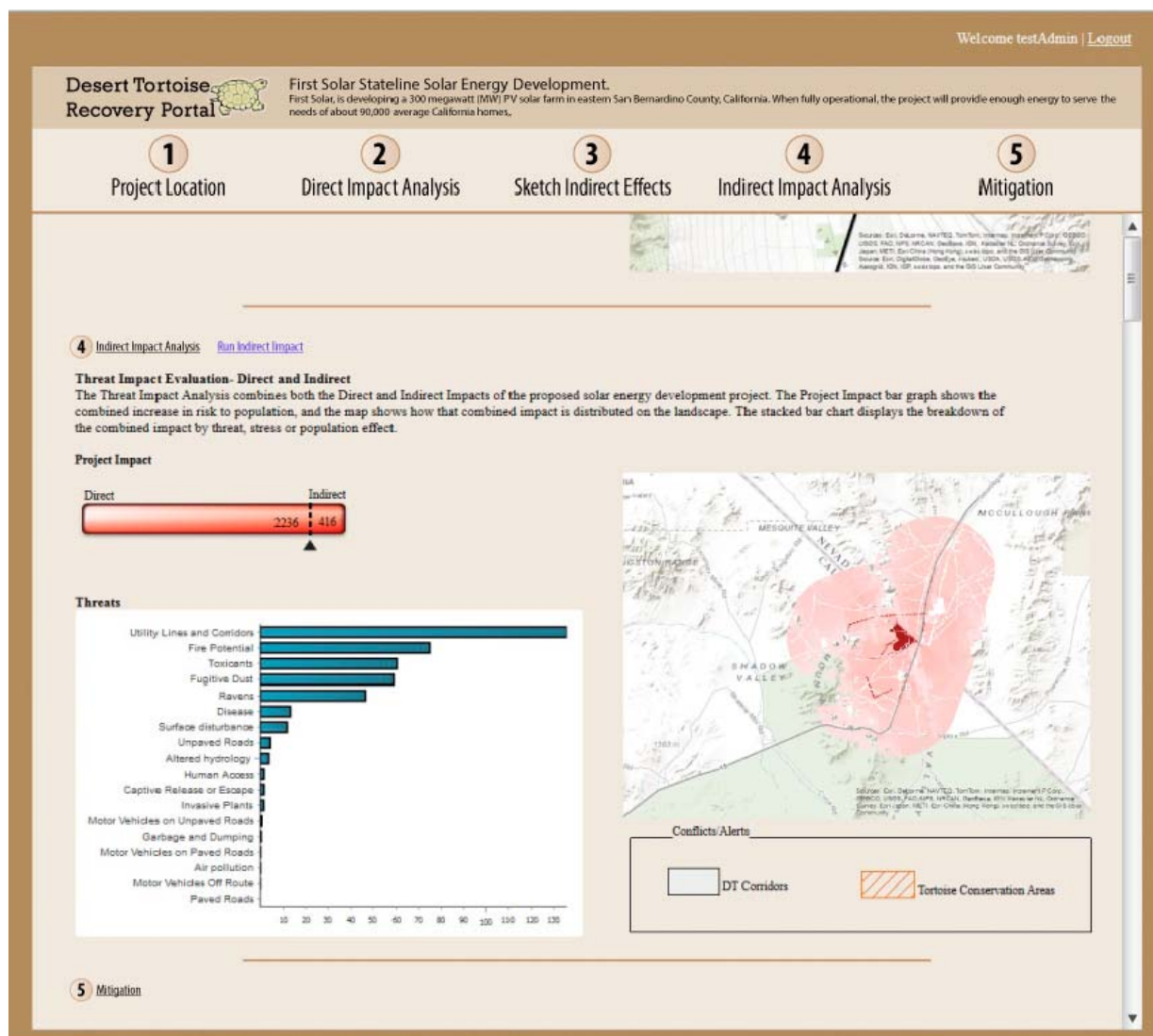
4.6.4.4 Analysis Step 4: Indirect Impact Analysis

Once these additional features and the project footprint have been entered, the system has a good “snapshot” of the new features that are planned on the landscape for the project. The system can then use the “cascading” indirect threat calculation (see Section 3.3.2) to predict other impacts such as a potential increase in ravens, dust, and/or human access. The user initiates the calculation by clicking on the “Run Indirect Calculation” link.

This calculation takes roughly an hour depending on the location and complexity of the project. The system will email the user when the analysis is complete. The core output is the estimate of the overall increase in risk to the population due to both direct and indirect impacts of the

proposed solar energy project. The indirect impact analysis results provide a map of the spatial variation of the expected impact. This map will have a greater extent than the sketched project features due to ecological effects in the cascading threat interactions. The tool displays a chart breaking down the impacts by a choice of threat, stress or population effects, to help the user to better understand the source of the impacts (Figure 55).

Figure 55: Dashboard with Step 4: Indirect Impact Analysis



Output from Step 4: Indirect impacts calculations are added to the Assessment Dashboard. The outputs include (a) a Project Impacts bar (red) showing the overall (direct and indirect) estimated increase in risk, (b) a chart showing the indirect increase in risk to the tortoise population broken down by threat (or stress or population effects) contributions, and (c) a map showing where the indirect increases occur.

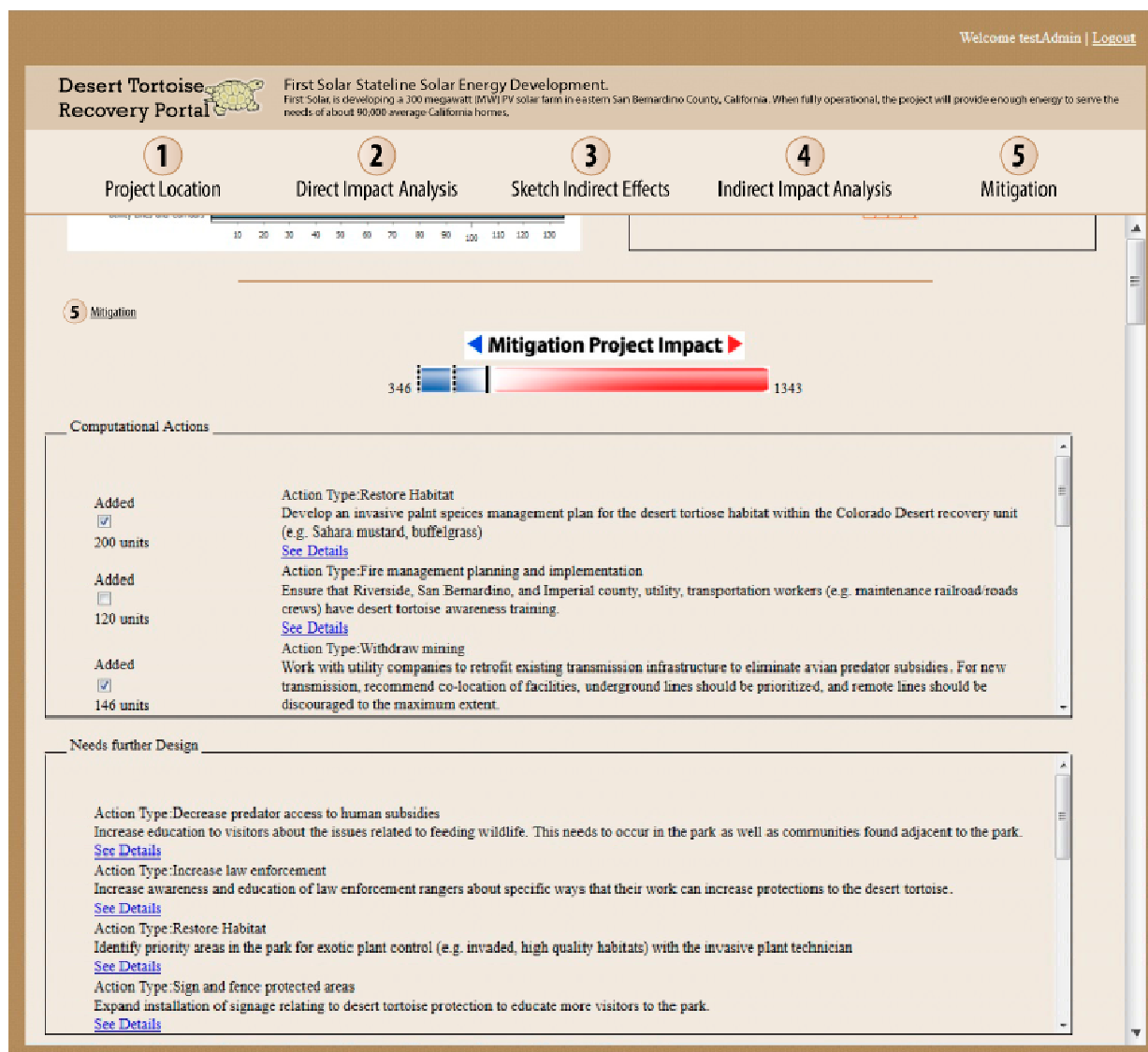
Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

4.6.4.5 Analysis Step 5: Mitigation

In this final step the system provides the user with a list of pre-calculated recovery actions that fall within the desert tortoise recovery unit of the proposed solar energy project. For a recovery

action to have its risk mitigation score pre-calculated, it must (1) have a status value of “Proposed;” (2) have been entered into the recovery action database as either area wide or with sufficient site-specific information that the Desert Tortoise SDSS was able to calculate its risk mitigation score (Figure 56).

Figure 56: Dashboard with Step 5: Mitigation Page



Output from Step 5: Mitigation: the user can select from the list of pre-calculated recovery actions (those in the list with active check boxes). As actions are added, their risk mitigation score is added to the total mitigation score (the blue bar in the risk offset bar chart at the top).

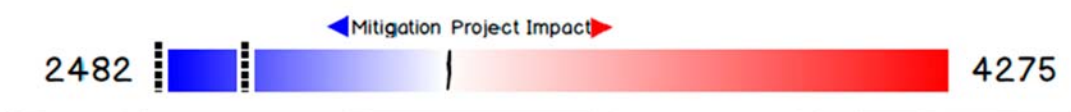
Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

Two lists of recovery actions appear on the dashboard. The first is a list of *Computational Actions*: those recovery actions from the database that have not been implemented already and were sufficiently spatially-specific to be pre-calculated. The second is a list of *Needs Further Design* recovery actions that have not been implemented, but are also not sufficiently defined to be calculable. In a future version of the system, the user will be able choose from this second list,

and return to the Recovery Action Manager and complete the design of that action. For this project, that list is for information purposes only to help users think more broadly about potential action types that may be appropriate for mitigation in the area.

In the Computational Actions list, the pre-calculated risk mitigation score appears under the checkbox to the left of the action. If the user checks the check box to include the recovery action in the mitigation suite, that score is added to the total mitigation score, and its addition increases the length of the blue bar on the impacts-mitigation risk offset chart above the lists (Figures 56 and 57).

Figure 57: Impacts-Mitigation Risk Offset Chart



In the Impacts-Mitigation Risk Offset Chart, the aggregate mitigation effects of all recovery actions checked in the Computational Actions list are represented to the left of the axis by the blue bars. The Overall impact of the proposed solar energy project is shown to the right of the axis by the red bar.

Source: Desert Tortoise SDSS, Third Iteration: Solar Project Impact and Mitigation Calculator

Finally, the user can either print the entire dashboard as a Web page or generate a PDF report.

4.6.4.6 System Test and Performance

As discussed earlier, several processing and performance enhancements were made over the course of the project to significantly speed up processing times. The web-based implementation of the spatial engines has a much more focused purpose and therefore requires fewer output products such as map layers and statistics. This focused purpose and the reduction of outputs have led to further performance gains.

To date we have run five complete tests of the web-based *Solar Project Impact and Mitigation Calculator*. These tests include the execution of both Direct Impact calculations and Indirect Impact calculations (for more on the difference between these calculations see sections 4.6.4.2 and 4.6.4.4). The processing time required to run these calculations is highly dependent on the size and location of the project footprint and its defined (sketched) indirect impacts. The time required to perform a Direct Impact calculation ranges from 13.6 to 20.4 seconds and averages 14.0 seconds. The time required to perform an Indirect Impact calculation ranges from 11.2 to 16.2 minutes and averages 15.6 minutes. This is a dramatic improvement for the user from the 30 minute calculation described in section 4.5.3.

The spatial engines are implemented as geoprocessing tasks using Esri's ArcGIS Server (AGS) 10.1 platform. The tasks are currently being executed on an Intel Xeon CPU E5-2670 processor at 2/6 GHz with 16 GB of RAM installed.

4.6.5 Discussion

The *Solar Project Impact and Mitigation Calculator* is aimed at project proponents, land managers and regulators. It will support them in running full mitigation calculations in a repeatable and reliable fashion, without requiring the direct support of the project team.

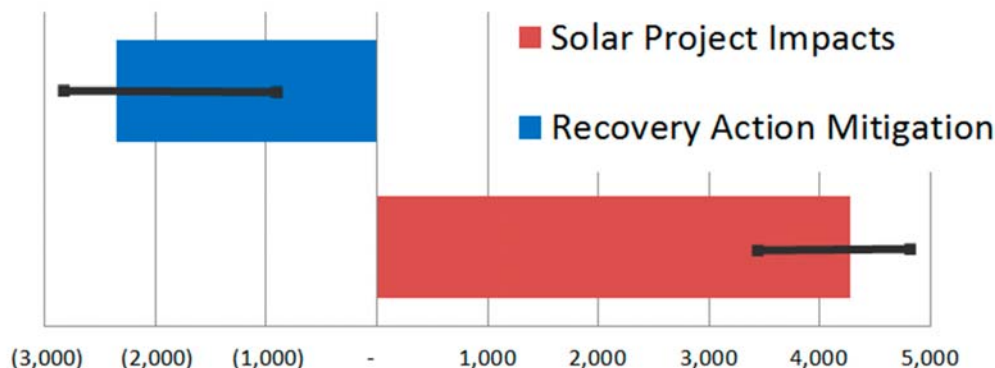
The newly enhanced system can help solve a key issue in desert tortoise recovery: scientists and local on-the-ground experts who have the species and local habitat knowledge to design highly effective recovery actions often do not have the resources to implement them. On the other hand, solar energy project proponents have the resources to fund effective recovery actions to mitigate the unavoidable impacts of their developments, but may lack the knowledge to develop the most effective suite of actions for this purpose.

By supporting the FWS Desert Tortoise RIT process, the project team was able to acquire over 800 prioritized recovery actions. In the process, the team learned that in the RIT collaborative setting, the participants tended not to design the actions to the spatially-specific scale that the Desert Tortoise SDSS needs to run calculations. Instead, it was often said by RIT participants that experts familiar with the local environment should finish the design. What that meant for the tool is that only a subset of actions are currently calculation-ready, and so additional recovery action design functionality that can support an expert in completing the design is needed. That is one of the tasks scheduled for the next iteration of the Desert Tortoise SDSS. Finally, in the future, the project team will work collaboratively to develop reporting templates based on individual agency needs.

4.7 A Start on Estimating Uncertainty in System Estimates of Risk

The Desert Tortoise SDSS is a complex computational system, whose outputs depend on both the input threat datasets and the many weights and parameters that describe the model. The ultimate system outputs are estimates for the increase in risk to the population posed by implementing solar energy development projects in desert tortoise habitat, and the decrease in risk achievable by implementing specific recovery actions for mitigation (Figure 58). Different values for the inputs, weights and parameters would likely result in different estimates of risk to the tortoise population. Although the system uses the best available data, weights and parameters, these estimates are not precisely known. Because the system outputs, which are estimates of risk, may be used to make important recommendations, it is essential to estimate the possible variance in these risk numbers and communicate this uncertainty.

Figure 58: Uncertainty Analysis: Change in Risk to Desert Tortoise Population



Desired results of the uncertainty analysis of the SDSS, where error bars can be assigned to both the increase in risk due to siting a solar energy project, and the reduction in risk due to the implementation of mitigating recovery actions.

Source: Desert Tortoise SDSS, Third Iteration

For a system this large, complex, and spatial, estimating uncertainty is a major task. This section describes initial steps taken to estimate the uncertainty in the outputs of the Desert Tortoise SDSS.

4.7.1 Uncertainty and Sensitivity of the System

The project partners are interested in both the uncertainty in the outputs and the sensitivity of those outputs to the various inputs of the system. *Sensitivity analysis* answers the question of which model components' variability (e.g., variability in inputs, weights, and/or parameters) are most responsible for system outcome uncertainty (Saltelli and Annoni 2010). Knowing this will aid future efforts to reduce the variability in those components and to efficiently reduce the output uncertainties. *Uncertainty analysis* focuses on quantifying the uncertainty in the outcomes, using error bars on the outcome values. Sensitivity analysis and uncertainty analysis are both used in the approach called *Output Variance Decomposition* (Saltelli and Annoni 2010).

The first step in this approach is to estimate the outcome uncertainty by repeatedly running the system with sets of values for all the components that are randomly generated, according to known statistical models of each components' variability. By subsequently running a series of experiments where only one component is varied at a time, output uncertainty can be decomposed to discern the overall contribution of a given component, including its interaction with other components, to the overall output (Lilburne and Tarantola 2009). From that one can estimate the sensitivity of the output uncertainty to the components' variability.

In the third iteration of the system, the project partners have begun implementing Output Variance Decomposition. The project partners estimated the variability in a subset of the system's components, and calculated the uncertainty in outputs based on repeated (10,000) runs of the system when those values varied accordingly. Not allowing for variance in all components of the system means that the uncertainty estimates produced must be treated as minimum estimates. These minimum estimates will likely increase when all, or at least most, of

the components are included in the uncertainty analysis. Because the computational infrastructure is not yet in place to complete the formal decomposition of the output uncertainty into the sensitivity of the individual components, for the present the project partners employed the less accurate sensitivity analysis obtained by varying each component's value *one-at-a-time* (*OAT Sensitivity Analysis*).

4.7.2 Uncertainty in Inputs and Components in the System

A subset of components of the Desert Tortoise SDSS were considered in these initial calculations of uncertainty (Table 7).

Table 7: Sources of Component Uncertainty in the Desert Tortoise SDSS

Component	Varied in Uncertainty Runs	Uncertainty Characterization
Input Threat layers	No	
Probability of Presence	No	
Threat-to-Threat Weights	No	Statistics on weights from multiple experts
Threat-to-Threat Ecological Effects Parameters	No	
Threat-Stress Weights	Yes	Statistics on weights from multiple experts
Threat-Stress Ecological Effects Parameters	No	
Stress > Population Effects Weights	Yes	Statistics on weights from multiple experts
Population Effects > Population Change	Yes	Spread in estimates based on various approaches to simplifying rates in Doak et al. (1994)
Recovery Action Effectiveness Weights	Yes	Expert estimation of nominal, minimum and maximum values

Sources of component uncertainty in the Desert Tortoise SDSS and whether they were included in the uncertainty analysis for this project.

Source: Desert Tortoise SDSS, Third Iteration

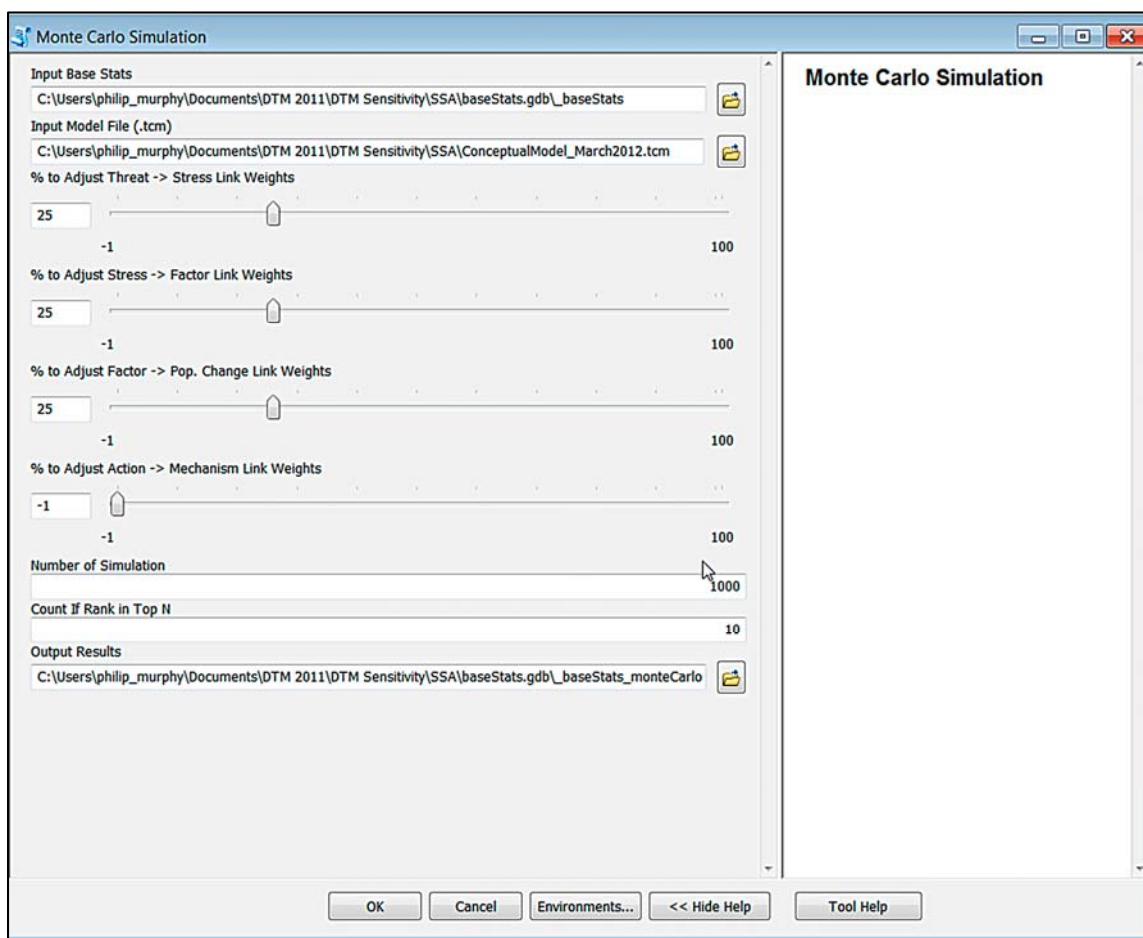
The parameters that describe ecological effects areas, typically a buffer distance for a linear decay, are not yet included in this analysis because varying their values involves spatial calculations that can be computationally intensive. Given the large number of runs of the systems required, this is not yet feasible.

As noted in Chapter 2, threat-to-threat contributions play no role in estimating the reduction in population risk due to the impact of a recovery action. However, they do play a role in estimating the increase in risk when a specific threat increases. As illustrated in Section 3.3.2, threat-to-threat contributions do not change the original threat layers; instead they add an additional surface element to the existing layers. Changes in spatial outputs for the many indirect threat pathways need to be calculated, so the present variance in these weights is not included in the uncertainty analysis. The project partners are working to establish a sound method to characterize variability in input spatial layers (threats and probability of presence), both in terms of attribute and location variance, for future iterations of the system.

4.7.3 The Spatial Sensitivity Analysis Module

Dr. Arika Ligmann-Zielinska had developed an add-in to Esri's ArcMap® software to implement global sensitivity analysis, where the values of weights that were allowed to vary are all randomly sampled simultaneously using a Monte Carlo approach (Figure 59). In a parallel project with the DTRO, she provided the Redlands Institute with a copy of the source code. This code was used to build a *Spatial Sensitivity Analysis (SSA) Module* for the Desert Tortoise SDSS.

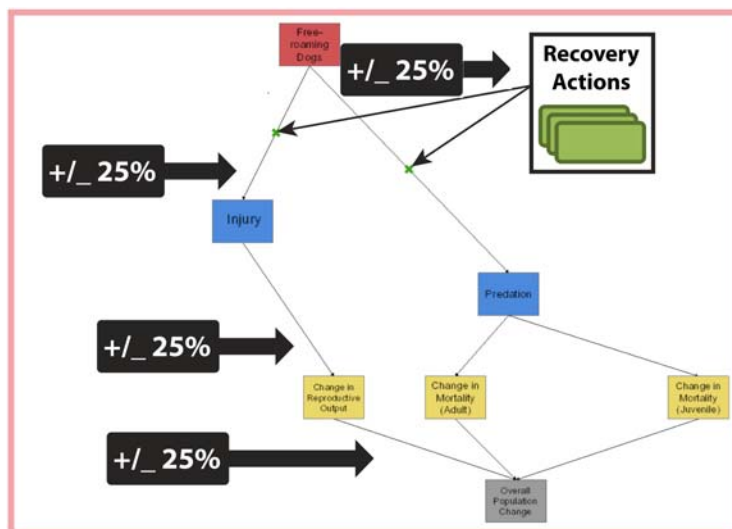
Figure 59: Spatial Sensitivity Analysis Module for the SDSS



User Interface for the Spatial Sensitivity Analysis Module, an SDSS tool that runs in ArcMap®.

Using the SSA Module, variability can be independently set for threat-to-stress weights, stress-to-population effects weights, population effects-to-population change, and for recovery action effectiveness weights (Figure 60).

Figure 60: Variability in Weights at Each Level in the Conceptual Model



Weights distributions can be set independently for weights between each level in the conceptual model. In this case all weights were set to have normal distribution about their point values with standard deviation of 25 percent of those point estimates.

Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

4.7.4 Input Uncertainties Modeled in the Third Iteration SDSS

The weights used in the uncertainty and sensitivity analysis in this third iteration of the Desert Tortoise SDSS were varied (Table 8).

Table 8: Weights Variation Used in Uncertainty Calculations

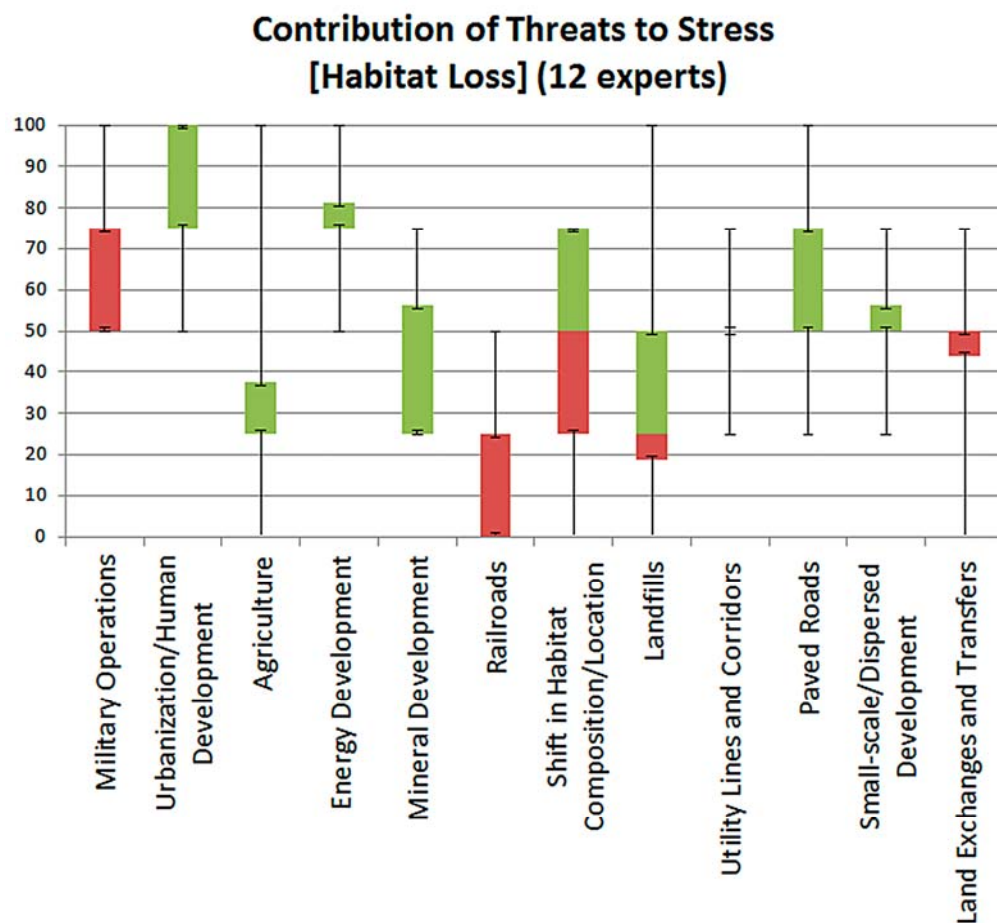
Components	Number	Characterization
Threat-Stress Weights	108	Normal +/- 25%
Stress > Population Effects Weights	44	Normal +/- 25%
Population Effects > Population Change	4	Normal +/- 25%
Recovery Action Effectiveness Weights	166	Uniform, Individual Min/Max

Weights variation used in uncertainty calculation for third iteration of Desert Tortoise SDSS

Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

Weight variations for threat-to-stress weights are estimated as normal distributions, based on the variation in experts' estimates on the online weights survey done in 2007 (Figure 61).

Figure 61: Example of Variation in Estimates of Contribution Weights



Example of variation in estimates of contribution weights of the threats that contribute to the stress of Habitat Loss. The red bars indicate values that fall in the 50 to 25 percentile interval below the mean; the green bars indicate values that fall in the 50 to 75 percentile interval above the mean, the mean being at the point where the red bar meets the green bar. The top whisker runs from the 75 percentile boundary to the maximum value, the lower whisker runs from the 25 percentile boundary to the minimum value. With only 12 weights (from the 12 experts) providing the data for each threat, a percentile region may be empty (where the colored bar is missing).

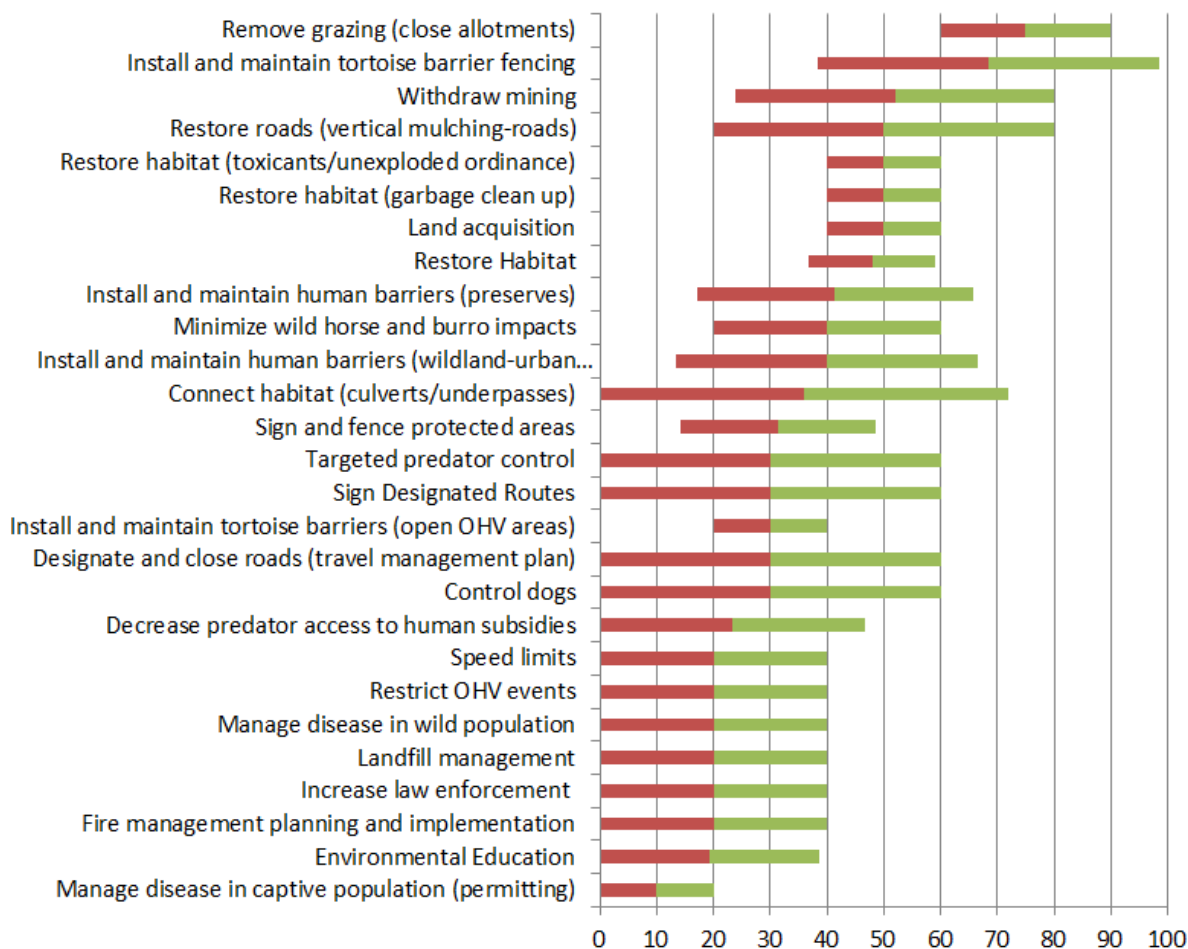
Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

The current version of the SSA Module supports a single variance model for all threat-to-stress weights. The project partners calculated an average standard deviation for all the threat-to-stress weights in a two steps: (1) calculating the standard deviation of the values from all 12 experts for each threat-to-stress link; and (2) taking the ratio of that standard deviation divided by the mean value for the weight, and averaging that relative standard deviation over all threat-to-stress weights.

In addition to estimating nominal recovery action effectiveness weights for each recovery action as it acts on threat-stress mechanisms (166 recovery action-threat-stress triplets), minimum and

maximum values were also estimated. The wide bands in Figure 62 show that for some recovery actions, their effectiveness is not well known, either in the literature or among field biologists or managers. For some action types that have very broad effectiveness values (e.g., Environmental Education), the issue is that there are many very different action sub types grouped together (e.g., signage, media campaigns, kiosks, school programs) that have very different effectiveness at different scales. The value of the effectiveness weight used will depend on the specific design proposal.

Figure 62: Expert Estimates of Variance in Effectiveness Weights for Recovery Actions



Expert estimates for average nominal, minimum and maximum effectiveness weights for recovery actions. A value of 100 means the recovery action is 100% effective in suppressing all threat-stress mechanisms it affects. The average nominal effectiveness weight value is where the red bar meets the green bar. The average minimum estimated effectiveness weight value is indicated by the left end of the red bar, the average maximum estimated effectiveness weight value by the right end of the green bar.

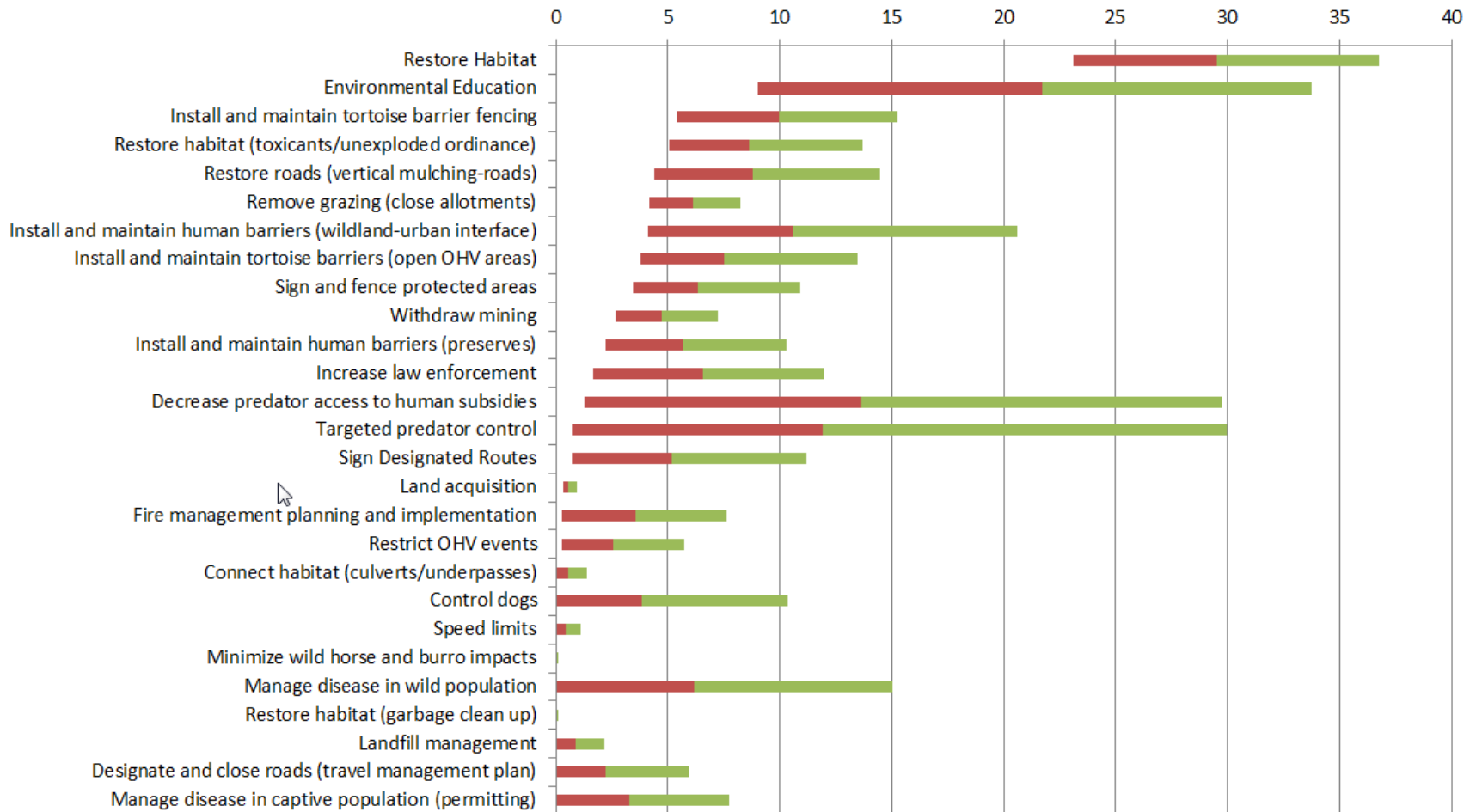
Source: Desert Tortoise SDSS, Third Iteration

4.7.5 Case Study: Uncertainty for Range-wide Recovery Actions in the Western Mojave

To test the approach described above, the project partners considered a study area consisting of the Western Mojave (WEMO) recovery unit (see Figure 2). As an exercise and in the absence of

site specific recovery actions, recovery actions were considered to be implemented over the entire study area. Based on Monte Carlo simulation of 10,000 runs, with the weights variation as described in Table 6, the uncertainty in recovery actions risk reduction estimates was calculated. As can be seen, the uncertainty for different recovery action types varies considerably (Figure 63). This reflects both the great uncertainty in the recovery actions effectiveness weights and the additional uncertainty generated by the contribution weights for threat-to-stress weights, stress-to-population effects weights, and population effects-to-population change.

Figure 63: Uncertainty in Risk Reduction Estimates for Recovery Actions in WEMO



Minimum uncertainty in recovery actions for recovery actions implemented throughout the Western Mojave region. The estimated mean value is where the red bar meets the green bar. The estimated value using the minimum effectiveness weight is indicated by the left end of the red bar; the estimated risk reduction value using the maximum estimated effectiveness weight is indicated by the right end of the green bar.

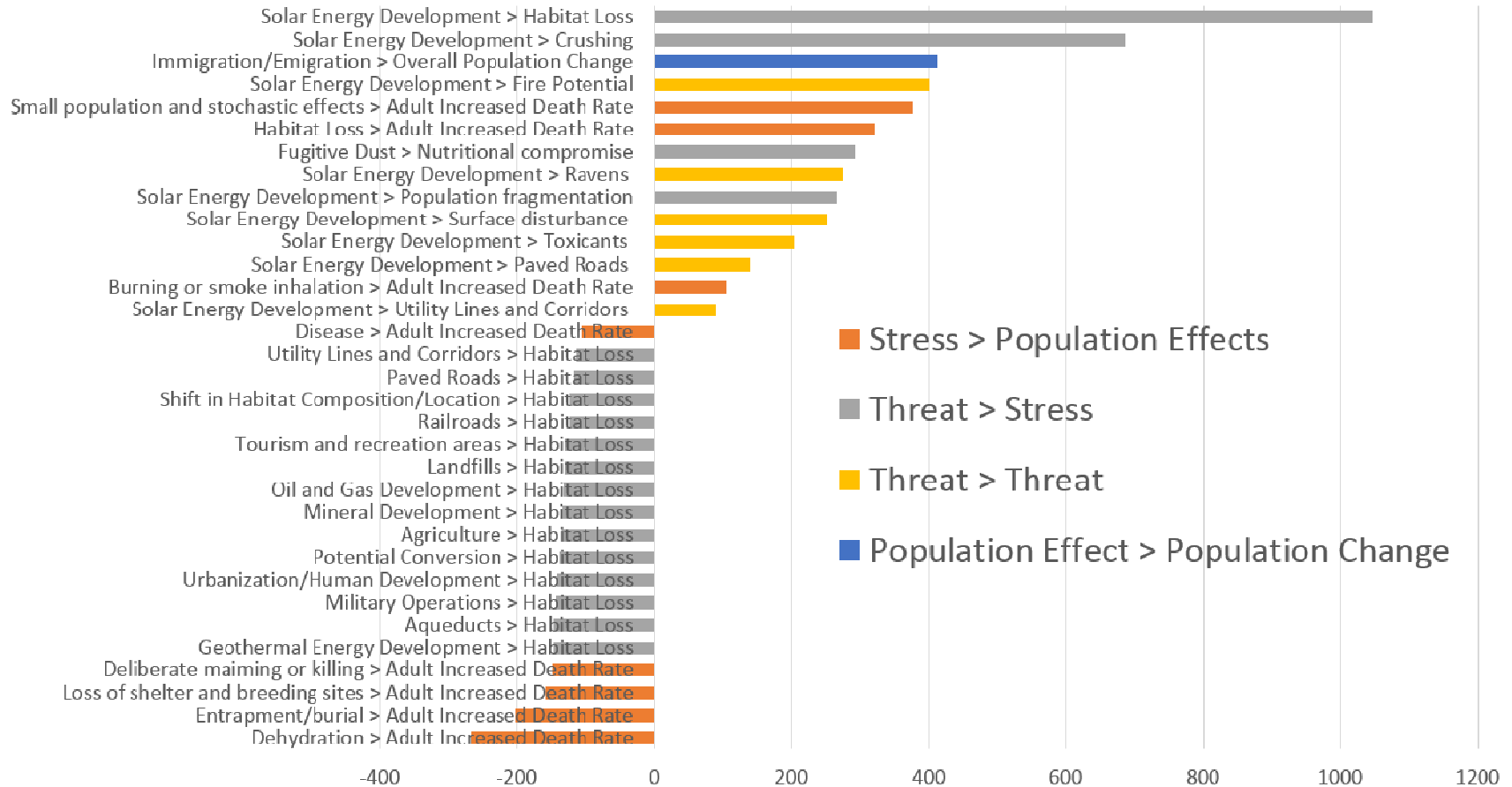
Source: Desert Tortoise SDSS, Third Iteration

4.7.6 One-at-a-time (OAT) Sensitivity Analysis

To explore how sensitive the impacts and mitigation outputs are to the 497 weights that the SSA scripts currently can vary, the project partners conducted a one-at-a-time (OAT) sensitivity analysis for the ISEGS project. In this analysis, each individual weight was varied by 0.1 (on a weights scale that varies from 0 to 1), while all other weights were kept at their nominal values, and the impact and mitigation calculations were executed. The purpose was to see, for a common unit change, to which weights is the model most sensitive. While in theory it is better to choose a smaller change increment, using 0.1 ensured that there would be observable changes in the outputs. For each weight, the difference was then calculated between the impact and mitigation risk change values for those outputs at the nominal weight value and its nominal weight value +/- 10% (Figure 64 and 65). For example, if a weight was already at 0.95, then the project partners used the nominal value less 0.1 and the nominal value. When a weight value was changed, its weighting set was renormalized.

Figure 64: OAT Sensitivity Analysis for ISEGS 2011: Impacts

Change in ISEGS 2011 Impacts with 10% shift in weight OAT



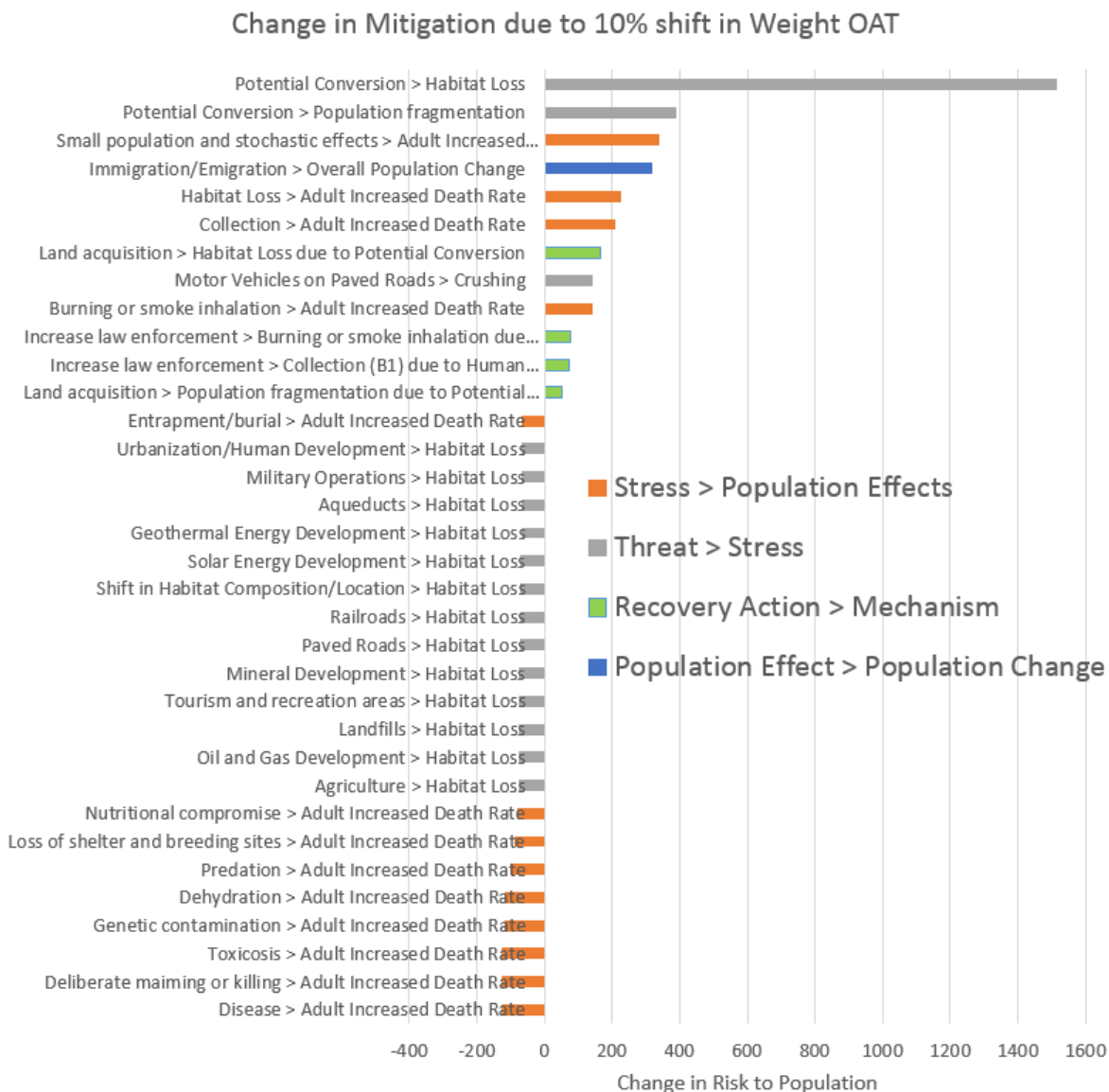
The graph shows the difference in estimates of increase in risk to population due to ISEGS calculated with each weight's value individually varied from its nominal value to nominal value +/- 10% values. Only weights for which this variation produced differences of at least 2% of the original impacts estimate of 4,275 are shown. For example, an increase of 0.1 in the weight that quantifies the contribution of the threat of "Solar Energy Development" to the stress of "Habitat Loss" produced the largest difference in estimated impacts due to ISEGs 2011. The bars are color coded by the types of the weights.

Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

By far the largest contributions to the estimated impact from ISEGS 2011 come from increases in the stresses of “Habitat Loss” and to a lesser extent, “Crushing” (Figure 4 in Appendix F). These stresses in turn are the two largest contributors to the Population Effect “Adult Mortality,” which is by far the largest contributor to “Overall Population Change.” Not surprisingly, any increase in the weights associated with those relationships significantly increases the overall estimated impact. Conversely, an increase in any weight that, through weights normalization, decreases any of those previous weights, leads to a drop in overall estimated impacts because the sum of all the weights for each threat that contributes to the stress of “Habitat Loss” (and, in turn, all other stresses) add up to 100%. So if one weight is increased from its nominal value, the weights representing the contribution of all the other contributing threats are decreased proportionately so that the entire set of the weights still add to 100%.

Of the 497 weights individually varied in the course of this OAT analysis, the variation by 0.1 (10% of the entire available weights range) of 222 of those weights produced no change in the estimated impact. That is because they either were (a) effectiveness weights for recovery actions, which play no part in this impact calculation; or (b) they were threat-to-threat or threat-to-stress weights that happen to be unrelated to the specific threat of solar energy development and its indirect effects. For although the cascade of affected threats and stresses shown for Solar Energy Development (as shown in Figure 25) touches many of the links in the conceptual model, it does not encompass all threat-to-threats and threat-to-stress links for other unrelated threats in the system.

Figure 65: OAT Sensitivity Analysis for ISEGS 2011: Mitigation



The chart shows the difference in estimates of the decrease in risk to population due to the ISEGS 2011 suite (final) of proposed recovery actions, calculated with each weight's value individually varied from its nominal value to nominal value +/- 10% values. Only weights for which this variation produced differences of at least 2% of the original total mitigation estimate of 2,355 are shown. For example, the weight that quantifies the contribution of the threat of "Potential Conversion" to the stress of "Habitat Loss" produced the largest difference in estimated mitigation due to the suite of Recovery Action considered for ISEGS 2011. The bars are color coded by the type of weight.

Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

The project partners conducted a similar OAT sensitivity analysis for change in mitigation at ISEGS (Figure 65). Recovery actions involving "Land Acquisition" accounted for 1,047 or 44%, of the total estimated reduction in risk to population due to mitigation (the second "New Table 1" in Appendix F). Land Acquisition recovery actions are 50% effective in reducing the threat of "Potential Conversion," which in turn leads to the stress of "Habitat Loss," which is the largest

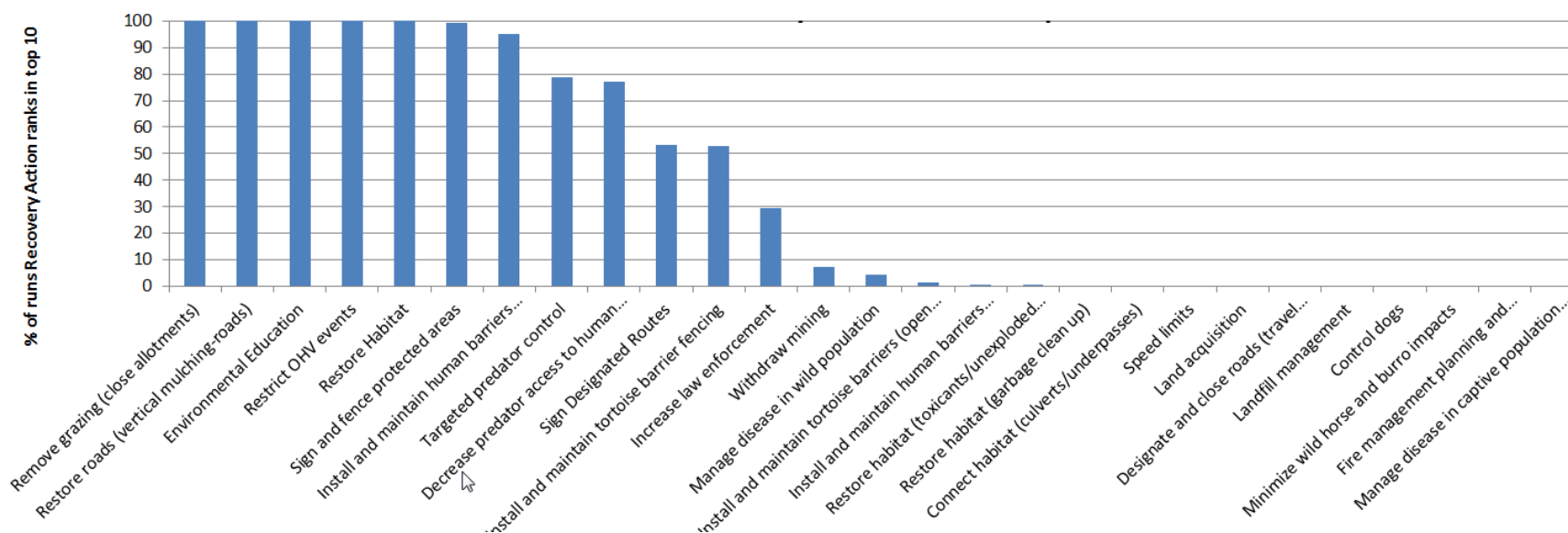
contributor to the population effect of “Change in Mortality (Adult),” which in turn is the overwhelming contributor to “Overall Population Change.” In addition, “Potential Conversion” contributes to the stresses “Population Fragmentation” and “Small Population and Stochastic Effects,” which in turn contribute to population effects “Change in Immigration/Emigration” and “Change in Reproductive Output” respectively. Not surprisingly, increases to those weights, or any weights in their associated causal chains, provided the largest estimated decrease in risk from mitigation. Conversely, increases in other weights that through normalization decrease those weights, result in decreases in the estimated totals.

Of the 497 weights individually varied in the course of this OAT analysis, the variation by 0.1 (10% of the entire available weights range) of 305 of those weights produced no change in the estimated decrease in risk to population. That is because they either were threat-to-threat weights that play no part in any recovery action calculations, or they are effectiveness weights for types of recovery actions not included in the ISEGS 2011 mitigation suite or threat-to-stress weights that are unaffected by the specific recovery action types included in the ISEGS 2011 mitigation suite.

4.7.7 Uncertainty Analysis across Tortoise Critical Habitat Areas

The same uncertainty analysis approach can be used at different spatial scales. The project partners investigated the variation of uncertainty across the thirty tortoise conservation areas (TCAs). For a resource manager considering which recovery actions to implement, the individual risk reduction score may not be as important as the relative ranks of those recovery actions. The project partners calculated the rankings of each recovery action (again implemented across the entire TCA) in each TCA for 1,000 Monte Carlo simulations and counted the number of times that each recovery action scored in the top ten for risk reduction, again using the variability settings from Table 5. For example, in the Ord Rodman critical habitat unit, six recovery actions always ranked in the top ten despite the variation in settings (Figure 66).

Figure 66: Results of Uncertainty Analysis for Ord Rodman TCA

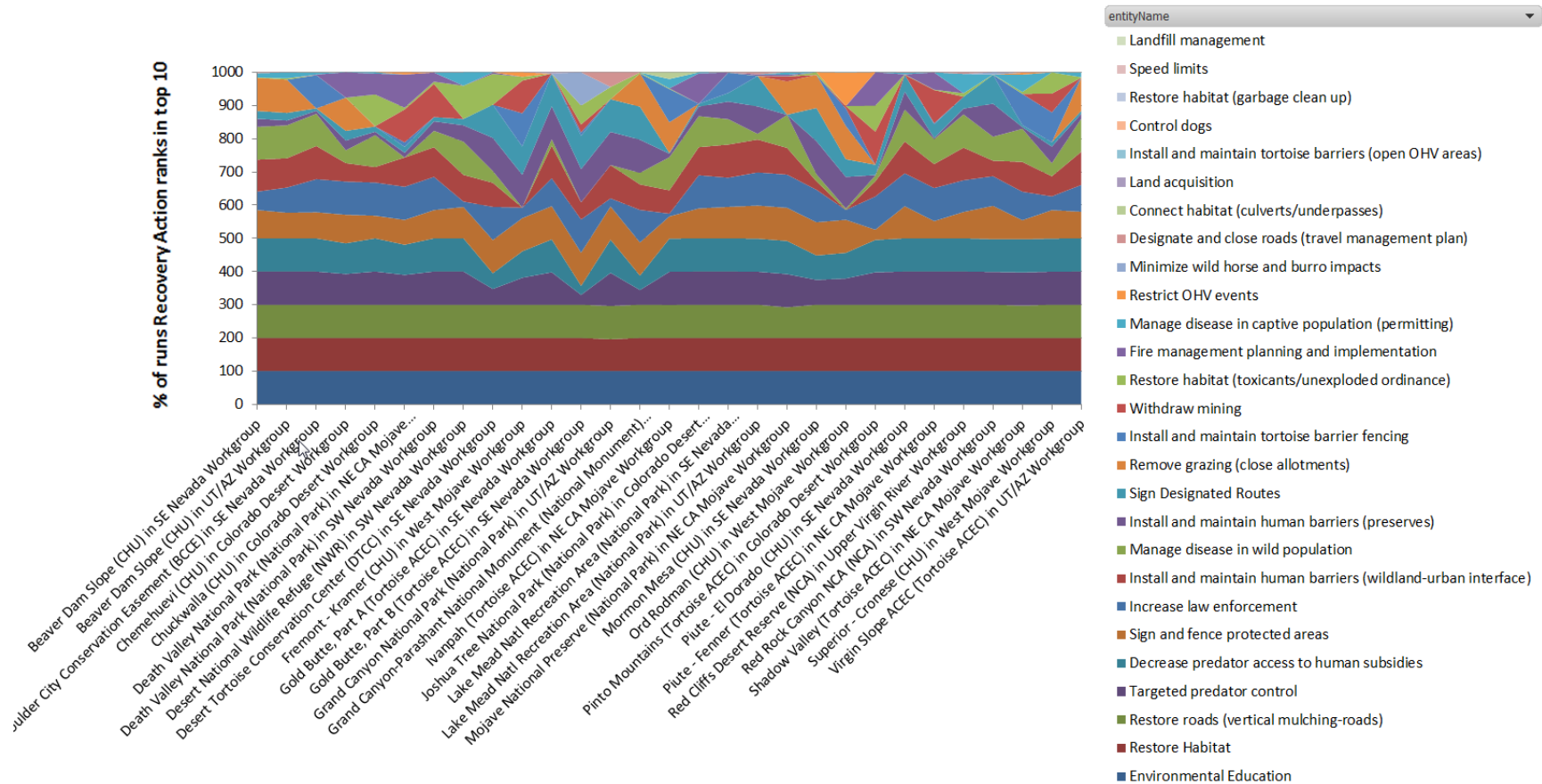


The results of the uncertainty analysis for Ord Rodman TCA. The graph shows how often over 1000 simulations (as a percentage) with weights varying as per Table 5, each recovery action ranked in the top ten for risk reduction. For example, “Removing grazing” always remained in the top ten, while “Managing disease in captive population” never appeared in the top ten.

Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

In gathering the ranking results for all the TCAs together, the project partners found considerable variation in the top ten recovery actions for each TCA. The project partners also found that a number of recovery actions (“Restore Habitat,” “Restore Roads (vertical mulching-roads),” “Environmental Education” and to a lesser extent “Targeted Predator Control”) were all in the top ten for all TCAs almost 100 percent of the time (Figure 67). Note that these are “artificial” recovery actions as it is not feasible to implement most recovery actions over an entire TCA.

Figure 67: Consistency in Rankings of Recovery Actions in Top Ten across TCAs



If a recovery action type is estimated to stay in the top 10 most effective recovery action types in a given Tortoise Conservation Area for all 1,000 simulations, it scores 100. Those recovery action types at the bottom of the graph did stay in the top 10 across all TCAs for all simulations. Further up the image, other recovery option types were most effective in some TCAs, less effective in others. The order of recovery actions in the graph is the same as that in the legends.

Source: Desert Tortoise SDSS, Third Iteration: Spatial Sensitivity Analysis Module

4.7.8 Discussion on Sensitivity Results

The work done in this project indicates that a global spatial sensitivity analysis approach is computationally feasible, despite the complexity of the model and the size of the desert tortoise range. Two major improvements need to be made in order to achieve error bars for both the increase in risk from the solar project and decrease in risk from a suite of site specific recovery actions, illustrated in Figure 57. The first is to characterize the variability of more of the system components listed in Table 4, and to improve the characterization of those used in this project to date. The second is to implement the threat-to-threat weights variations and calculations in order to generate the uncertainty of proposed solar projects. Both of these improvements are the subject of research in a second project grant from the California Energy Commission.

The OAT sensitivity analysis provided insight into which weight's unit variance created the most change in both the estimated impact of the ISEGS 2011, and the estimated set of recovery actions proposed for mitigation. What was striking was how insensitive the SDSS outputs were to all but a few of the 497 weights included in the analysis. Similar analyses need to be performed for a diverse set of solar energy development proposals before findings that are not specific to the ISEGS 2011 proposal can be established.

Finally, the project partners will need to complete the Output Variance Decomposition program outlined at the beginning of this section to get a more complete estimate of the impact of individual components to the uncertainty of risk outputs of the model.

CHAPTER 5:

Conclusions

5.1 Project Achievements

The project partners extended the pre-existing Desert Tortoise Spatial Decision Support System to support environmental review of new solar energy development projects and potential mitigation options. Improvements to the data, models, calculations and technology empower regulators, resource managers, and other users to quantify the direct and indirect impacts of proposed projects, and to better assess the mitigation value of recovery actions to compensate for those impacts on the tortoise population. This project also developed a Web-based portal with four online tools, where users can input solar energy project footprints to conduct spatially-explicit and fully documented combined impact analyses and to evaluate mitigation options for the desert tortoise.

The project team also used these online tools to engage partner agencies and stakeholders in review and validation of system data, and conceptual and computational models, to ensure that the system is using the best available data and science. This effort involved extensive collaboration with the FWS Desert Tortoise Science Advisory Committee and the multi-agency Desert Tortoise Recovery Implementation Teams, among others.

5.1.1 System Improvements

The first and second iterations of the Desert Tortoise SDSS laid the foundation for calculating the effectiveness of recovery actions and reducing risk to the tortoise population. In this project the research team achieved the following significant improvements with the third system iteration:

- Conducted a deep review and revision of the system conceptual model with scientific experts and stakeholders to incorporate current science and literature, and to develop the areas of the model concerned with solar energy development project impacts.
- Improved the system's ability to assess the relative value of recovery actions, by placing impacts and recovery actions on the common scale of risk to the tortoise population.
- Incorporated additional datasets and expert input from partner agencies and stakeholders through workshops, discussions, and presentations. Current spatial data holdings include 288 threat layers, 147 of which are used in the system, and 180 base data layers, making this system the premier data source for Mojave desert tortoise.
- Performed extensive data acquisition, review, and curation activities including data inventory, summary data description reports and detailed FGDC-compliant metadata. Assessed the potential to integrate formal models of desert tortoise population dynamics or demography, by exploring several alternative approaches.
- Tested the system by calculating impacts from a proposed site-specific solar project, and the associated suite of proposed mitigation actions.

- Made extensive improvements in the computational efficiency and functionality of the SDSS to assist users.

5.1.2 Project Leverage

This project builds on over a decade of applied research on the Mojave desert tortoise by the project partners through funding from FWS and the Department of Defense/Army Research Office, Bureau of Land Management (BLM), U.S. Marine Corps and in collaboration with multiple stakeholders including the Desert Tortoise Management Oversight Group, California Desert Managers Group and other local, state and regional groups.

This project also leveraged scientific research, new system components and other improvements completed with concurrent funding from FWS. This included scientific research funded by the FWS that informed efforts to integrate formal population dynamics modeling into the system. Engaging with other planning efforts currently underway, including the multi-agency desert tortoise Recovery Implementation Team process, provided unique opportunities for validation of conceptual models and data.

5.2 Challenges

In completing this research, the project partners identified a few key challenges:

- Including large-scale processes such as population fragmentation in the system, to fully address long-term cumulative impacts. Currently, the effects of population fragmentation are treated in the SDSS merely as a local increase in risk based on whether or not the fragmenting threat is located within an identified priority habitat corridor (Averill-Murray et al. 2013). The project partners intend to explore alternative approaches to estimating the effects of fragmentation and how these may be integrated in the SDSS calculations. This is particularly an issue for large scale solar energy development projects.
- Fully assessing the long-term and cumulative effects of numerous solar energy development projects in the desert. Currently, the changes in threats, stresses, and population are modeled as linear responses to either increases in threats or the implementation of recovery actions. While this approach allows for combined analyses of both direct and indirect effects, it does not model for thresholds in population or habitat responses, plus it assumes the effects of threats and stresses are considered independent. However, when the increase to a threat is not small compared to the current spatial extent of that threat and many large-scale threats are being located close together within tortoise habitat, linear modeling may no longer be appropriate.
- Incorporating improved land use change models to better determine the effects of land acquisition proposals for mitigation. Currently, the recovery action of acquiring land for conservation is treated in the SDSS as a reduction in the threat of “Potential Conversion,” where this threat is greatest inside the tortoise conservation areas, moderate in habitat linkages, and least in the remaining habitat. In reality, land parcels

face different levels of threat from urban development and other human uses. Therefore the benefit of acquiring land should reflect the actual level of risk averted by protecting it. Improved land use change models could better estimate this threat.

5.3 Recommendations

The project team also identified some specific, high-value analysis and technology development activities that could further enhance the system's utility for environmental review of energy developments:

- Improve impact and recovery models (e.g., the land acquisition model) to better assess the relative value of recovery actions at the project-specific scale.
- Characterize and integrate uncertainty for additional components of the system to provide a more comprehensive estimate of uncertainty around system estimates.
- Continue to improve system processes and user interfaces for design and selection of site-specific recovery actions as potential mitigation for solar energy development projects.
- Extend the models to better address the large-scale and long-term cumulative effects from processes such as population fragmentation and climate change. Cumulative effects are the total combined effects (direct and indirect) of multiple threats that accumulate over space and time.

5.4 Next Steps

In 2012, the California Energy Commission awarded a second grant to FWS and Redlands to build on the success of this project and further develop the Desert Tortoise SDSS for review of solar energy development projects and potential mitigation options. The goals for this second project are to strengthen specific aspects of the scientific basis of the underlying data, models and analysis, and to improve system computational and reporting functions so that the Energy Commission and other agencies may more rapidly and efficiently obtain estimates of impacts and evaluate mitigation scenarios for proposed projects.

Building on the recommendations noted above, specific objectives of the second project are to:

- Improve existing impact and recovery models to evaluate the direct and indirect effects of solar energy development projects on the desert tortoise at the project-specific scale, and better assess the relative recovery value of management actions for mitigation.
- Provide scientifically-robust results with appropriately characterized measures of uncertainty to regulatory agencies to help inform decision-making both at the project-scale, as well as at the landscape-scale.
- Develop tools to support efficient evaluation of multiple proposed solar plants and recovery action portfolios.

These capabilities will be integrated into an enhanced version of the Desert Tortoise Recovery Portal developed in the first project that facilitates improved access all the tools and information in the Desert Tortoise SDSS (data, maps, and reports as well as system models and functionality) through a standard Web browser.

It is worth noting that, while the current system focuses on desert tortoise and on solar energy developments, the methodology and framework used in this project are adaptable to other geographies, sensitive species (e.g., Mohave ground squirrel), and renewable energy technologies (e.g., wind). The system architecture is designed to incorporate updated and new inputs (data, information, knowledge) produced by other landscape-scale planning efforts and research, as these become available. While the scientific knowledge contained in the current system conceptual model is specific to Mojave desert tortoise recovery, the Conceptual Model Manager tool and the methods from this project may be used to create new conceptual models for other priority species or regions (Darst et al. 2013). The structure of the conceptual model is derived from an accepted species-independent conservation lexicon (Salafsky et al. 2008) and the system framework and tools for conducting threats assessment, identifying recovery actions, and integrating related data and knowledge, can be applied to any at-risk species.

For example, the potential to leverage and repurpose the decision support methods and tools developed in this project led to an invitation for Redlands to collaborate with the FWS Region 6 and national branch of Conservation Integration on the Landscape-Scale Energy Action Plan (LEAP). The LEAP project is developing decision support tools for addressing the anticipated impacts of renewable energy development (primarily solar and wind) on multiple sensitive species in the Mountain-Prairie region.

5.5 Benefits to California

The Desert Tortoise SDSS provides critical support for solar energy project proponents, scientists, regulators, resource managers and other users to assess the combined effects, both beneficial and adverse, of various activities, management actions and policies on the desert tortoise. The system is helping to reduce conflict among multiple stakeholders by providing a common language and an explicit, shared model for the impacts of diverse threats and the effectiveness recovery actions. Natural resource managers are using the system to inform multi-agency planning efforts.

As the state energy demand continues to increase, seeking alternative sources of renewable energy is of vital importance. Initial assessments with the decision support system confirm that the new generation of large-scale solar energy developments could indeed have significant impacts on the recovery of the Mojave desert tortoise. Therefore, it is ever more important to identify the most effective recovery actions that could offset these impacts.

Through its focus on timely, science-based support for the environmental review process for solar energy development, this project supports agencies in making better decisions to promote conservation, while reducing uncertainty and delays in the permitting process for the benefit of California's ratepayers.

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Useful Resource Links

California Energy Commission website: <http://www.energy.ca.gov/>

Desert Managers Group: <http://www.dmg.gov/>

Desert Tortoise Council: <http://www.deserttortoise.org/>

Desert Tortoise Preserve Committee: <http://www.tortoise-tracks.org/>

Desert Tortoise SDSS Data Explorer: <http://www.spatial.redlands.edu/dtro/dataexplorer>

Desert Tortoise SDSS Model Explorer: <http://www.spatial.redlands.edu/dtro/modelexplorer/>

Desert Tortoise SDSS Recovery Portal: <http://www.spatial.redlands.edu/cec>

Fish and Wildlife Service, Desert Tortoise Recovery Office:
http://www.fws.gov/nevada/desert_tortoise/

Mojave Desert Ecosystem Program (MDEP): <http://www.mojavedata.gov/>

GLOSSARY

Acronyms

Acronym	Definition
AHP	Analytic Hierarchy Process
BLM	Bureau of Land Management
CDFG	California Department of Fish and Game (now California Department of Fish and Wildlife)
CESA	California Endangered Species Act
DoD	Department of Defense
DRECP	Desert Renewable Energy Conservation Plan
DTRO	Desert Tortoise Recovery Office of the U.S. Fish and Wildlife Service
ESA	Endangered Species Act
FGDC	Federal Geographic Data Committee
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
ISEGS	Bright Source's Ivanpah Solar Energy Generating Station
LEAP	Landscape-Scale Energy Action Plan
MCDA	Multi-Criteria Decision Analysis
MDEG	Mojave Desert Ecosystem Program
NEPA	National Environmental Policy Act
NPS	National Park Service
OAT	One-at-a-time Sensitivity Analysis
PIER	Public Interest Energy Research program of the California Energy Commission
REAT	Renewable Energy Action Team
RIT	Recovery Implementation Teams for the Mojave Desert Tortoise
SAC	Science Advisory Committee to the FWS Desert Tortoise Recovery Office
SDSS	Spatial Decision Support System
SSA	Spatial Sensitivity Analysis

Acronym	Definition
STEP	Siting, Transmission, and Environmental Protection Division of the California Energy Commission
TCA	Tortoise Conservation Area
USGS	U.S. Geological Survey
WEMO	Western Mojave Desert Region

Terms

Term	Definition	Example
Absolute rate model	A model that estimates the absolute value of a demographic rate based on threats in an area	Annual juvenile mortality due to raven predation for a given distribution of ravens in an area
Affected threat	A threat that is either (a) contributed to by a specific threat, or (b) a threat suppressed by a specific recovery action	In the first system iteration, the threat of “Ravens” is suppressed by the recovery action of “Decrease predator access to human subsidies”
Carrying capacity	For a given region, carrying capacity is the maximum number of individuals of a particular species that resources can sustain indefinitely without significantly depleting or degrading those resources.	Threats to habitat may not result in direct mortality of individuals, but changes to carrying capacity which result from impacts to habitat can affect population numbers.
Computational model	Models containing mathematical equations or algorithms that simulate natural processes and use a set of input parameters to predict the outcome of these processes	The SDSS computational model expresses the elements and input parameters of the conceptual model as algorithms, which are then executed using GIS and other software programs.

Term	Definition	Example
Combined impacts / combined effects	All of the direct and indirect effects resulting from a specific threat	New solar energy developments present direct threats (e.g., “Habitat destruction”) and indirect threats (e.g., “New roads”), the totality of which represent the combined impact of this activity on desert tortoise.
Conceptual model	A representation of the set of causal relationships between factors that are believed to affect an at-risk species (Darst et al. 2013)	The Desert Tortoise SDSS uses a conceptual model to characterize the interrelationships among threats, tortoise population declines, and recovery actions.
Conservation action	Interventions undertaken to reach conservation goals and objectives (Salafsky et al. 2008)	See Recovery Actions
Demographic rates	The combination of population effects (mortality, reproductive output and immigration/emigration) with tortoise life stages (juvenile and adult)	The four demographic rates in the conceptual model are: change in adult mortality, change in juvenile mortality, change in reproductive output, and change in immigration/ emigration.
Direct effects of a threat	Pathways from threats to stresses to associated population effects on population risk (Darst et al. 2013)	The effect of (the threat of) “Ravens” on (the stress of) “Predation” leads to (the population effects of) Adult mortality and Juvenile mortality

Term	Definition	Example
Direct stress weight (second iteration)	The relative, range-wide contribution of a specific stress to overall population change	The direct stress weight sums the products of individual weights along the paths that link that stress to population effects, and the population effects to population change.
Direct weight (of a threat, first iteration)	The direct contribution of each threat to overall, range-wide mortality of adult desert tortoises.	In the first iteration, the system uses the direct weights to estimate risk to the tortoise population as a weighted overlay of all threats that contribute to mortality
Ecological effects area	Threats and recovery actions can affect an area greater than the “footprint” of where they exist themselves (threats) or are implemented (recovery actions)	An active mine gives rise to fugitive dust over a wide area, which is that threat’s ecological effects area
Effectiveness weight	An estimate of how effective a recovery action is in suppressing a threat or a threat-stress mechanism	A tortoise fence erected on both sides of a road can eliminate crushing due to motor vehicles on the road - an effectiveness weight of 1
Generations of indirect effects	First generation: effects of threats that proximately result from the focal threat. Second generation: effects of threats that result from generation 1 threats are second-generation indirect effects, etc. (Darst et al. 2013)	See Figure 25 showing cascading generations of threat increases due to an increase in a focal threat

Term	Definition	Example
Indirect effects of a threat	Pathways to population risk that lead from a threat through resulting threats rather than directly through stresses (Darst et al. 2013)	(The threat of) “Utility lines and corridors” contributes to (the threat of) “Ravens”, which in turn contributes to (the stress of) “Predation”
Layer	A surface on a map that when interrogated returns a value (often null) for any point on the map	A threat intensity layer
Link	An effect that connects two objects, represented visually as line connecting two nodes	The contribution a threat makes to a stress (threat-stress); for example, the contribution of “Ravens” to “Predation”
Normalization factor	The inverse of the total sum of any layer taken over every point (or raster cell) of the entire range	Multiply all values in a layer by its normalization factor to normalize the layer
Population effect	Change in mortality, reproductive output, or immigration or emigration in a population (Darst et al. 2013)	Change in mortality amongst juvenile tortoises
Probability of presence	A map layer representing the current probability of presence of the desert tortoise, as derived from the USGS habitat potential model after removing any impervious (paved, urban) surfaces.	The value of the probability of presence surface at a point indicates how suitable that area is for the desert tortoise. For those areas that have a high (close to 1) value but currently no desert tortoise population, a population may return and thrive there in the future, a critical consideration in terms of species recovery.

Term	Definition	Example
Raster data	GIS raster data is structured as an array of square cells (pixels) in geographic coordinate space where each pixel is coded with a single value (potentially more values based on format and data type constraints).	
Recovery	The process by which the decline of an at-risk species is arrested or reversed so that its long-term survival in nature can be ensured (Darst et al. 2013)	
Recovery action	A management action taken in support of desert tortoise recovery (Darst et al. 2013)	Tortoise fencing along roads is a recovery action designed to reduce mortality of tortoises from on-road traffic collisions.
Risk (first system iteration)	Contribution to tortoise mortality due to threats	In the first iteration, mortality was treated as a proxy for risk to the tortoise population.
Risk to the population (second system iteration)	Aggregate stress due to threats	In the second iteration, the system estimates the relative impact of threats and relative effectiveness of recovery actions based on their predicted effect on risk to the population.
Risk to the population (third system iteration)	Aggregate stress due to threats X Probability of Presence	In the third iteration, probability of presence was used to improve the calculation of <i>risk to the population</i> at each point across the range of the tortoise.

Term	Definition	Example
Scenarios	Formal versioning of the data, recovery action tracking and user comments from system component tools such as the Data Explorer and Model Explorer, as well as system inputs and outputs for particular computational runs.	In the third iteration SDSS, each system run has a unique scenario associated with it, its inputs and its outputs, so that project partners can compare results between system runs over time and even re-run a particular scenario or system version if necessary.
Sensitivity analysis	Sensitivity Analysis answers the question of which model components' variability (e.g., variability in inputs, weights, and/or parameters) are most responsible for system outcome uncertainty.	Changing the contribution weight of (the threat of) "Ravens" to "Predation" changes the estimate of the risk to the population.
Spatial constant layer	A spatial layer whose intensity is constant across the range of the desert tortoise	For stochastic (random) threats (e.g., storms and flooding), the SDSS uses a spatial constant layer to represent the baseline level of interaction with other threats and stresses.
Spatial decision support system	A method for breaking down a large problem into its component parts and identifying how those parts interact (Starfield 1997)	The Desert Tortoise spatial decision support system.
Spatial normalization	Procedure for rescaling a layer so that the sum of the values of the layer over the whole range is 1	Used to turn a threat layer with intensities in original units to a dimensionless, normalized layer

Term	Definition	Example
Stress	Degraded condition or “symptoms” of the species that result from a threat (Salafsky et al. 2008)	(The stress of) “Toxicosis” is the mortality or sublethal effects in the population due to effects of a poison or toxin.
Threat	Naturally occurring or proximate human activities that have caused, are causing, or may cause the destruction, degradation, or impairment of species (Salafsky et al. 2008)	Urbanization, Military operations, Paved Roads
Threats assessment	A systematic approach to assessing the relative importance of each threat to a species’ status (Darst et al. 2013)	By using the system estimates of relative contributions of a specific threat in an area, the threats present in that area can be ranked.
Threat intensity layer	A range-wide map layer whose value at each point represents the intensity of a specific threat at that point	The density of urbanization within the tortoise range
Umbrella species	A species with large area requirements whose protection may offer protection to other species within the required area	The desert tortoise is a wide-ranging umbrella species for the Mojave Desert, whose conservation offers protection to other co-habiting desert species.
Uncertainty analysis	Uncertainty analysis attempts to characterize the uncertainty (variability) in the outputs of a system based on knowledge of the uncertainty (variability) of the inputs and model parameters of the system.	Uncertainty in outputs of a system is often characterized by the use of error bars.

Appendices

Appendix A: Conceptual Model Elements and Descriptions

Appendix B: Demographic Modeling Report: Effects of threats on demography of Mojave desert tortoise

Appendix C: Table of Monitoring Metrics

Appendix D: Elasticity Calculation

Appendix E: Full Data Inventory for Desert Tortoise SDSS (2011)

Appendix F: ISEGS Impact and Mitigation Report to the California Energy Commission (2011)

These appendices are available as a separate volume, publication number:

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